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THE LUNAR BASE

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ABSTRACT

After describing the advantages of establishing the base, which would be constructed for the refuelling and maintenance of spaceships, an appraisal is made of the likelihood of minerals suitable for the preparation of propellants being available on the Moon. Methods and plant for preparing various individual propellants, power generation, and auxiliary equipment necessary for the welfare of the staff, etc., are then discussed. Finally the problem of the establishment of the base is considered.

Introduction

The advantages of the lunar base may be dealt with under three headings: (*a*) lunar life, research and exploration; (*b*) travel between the Earth and Moon; and (*c*) travel to other planets.

The establishment of some kind of a base is clearly essential for the proper study and development of our Moon. Whilst much topographical and geological information about the lunar surface could be gained from low-altitude flight above it by manned rockets, or better of rockets fitted with photographic or television cameras, nevertheless we shall not be satisfied until we can actually roam about the surface, until we can climb the lunar mountains, dig and mine. These exploring activities can be carried out over a limited area of the Moon's surface by foraging parties sent out from the first spaceships that land there, and in fact many such survey expeditions would be necessary before deciding on the practicability of the base, and its site. But operations based solely from a spaceship can only take place within restricted areas and must necessarily be completed as rapidly as possible, because of the limited stocks of air, food, water, equipment, etc., which can be carried. The lunar base, with its collection of buildings, stores, workshops, etc., will enable much more ambitious surveys to be undertaken. These surveys can be organized in a manner similar to those used in the Polar or Mount Everest expeditions—we have, of course, much to learn from the experiences of these expeditions and would do well to study them. Intermediate camps or caches of stores can be set up, and thus the range and duration of the surveys can be extended. Expeditions operating from a lunar base would also be able to devote the majority of their time to the collection of research material which could later be studied and analysed at leisure in the base.

It would, of course, be desirable to attach laboratories to the base. Some

rudimentary "works lab" would be essential to supervise the running of the propellant plant and the refuelling of the ship. But that would have to be expanded as soon as possible into a full-size research establishment for making astronomical observations, for studying the Moon, and for making experiments under the changed conditions that exist there. In fact, the setting up of the base is but the first step along the path to the adaption of the Moon to our purposes, just as the setting up of a ford or bridge centuries ago has led to the development of the great cities of to-day. Despite that, the facilitation of activities on the Moon arising from the establishment of the base is not the greatest advantage that may result.

One of the difficulties that has often been stressed, both in this Society and elsewhere, is that of propellants. Nearly four years ago A. V. Cleaver[1] stated that with propellants which might conceivably be developed, it was most unlikely that any rocket powered by chemical fuels would be capable of carrying any appreciable payload to the Moon, even though a multiple-step design be adopted; an atomic-powered rocket was more likely to be successful. In the series of papers on the Atomic Rocket[2] these views were reasserted, although it was pointed out that chemical motors would still be required for taking off and landing, to avoid the radioactive hazards connected with the use of a purely atomic rocket. A detailed study of such a composite circum-lunar rocket has already been made by Gatland, Dixon and Kunesch.[3] However, in the series of papers on the atomic rocket it was also stressed that even the most promising method of applying nuclear energy to rocket propulsion (i.e. the use of nuclear energy to heat up a working fluid) did not seem to offer great encouragement to our hopes of travel to the Moon and planets.

There are, however, methods of overcoming these difficulties, notably a method thought to have originated with von Pirquet. This involves the establishment of artificial satellites or orbital space-stations. In his paper "Orbital Bases," H. E. Ross[4] gave us a detailed analysis of an ingenious scheme embodying this principle. The advantages of these methods is not that the total fuel consumption for the Earth-Moon-Earth trip is less, but that the size (or mass ratio) of the rockets used is greatly reduced and that we are enabled to use the fuels at our disposal (which have comparatively small exhaust velocities). This follows from the fact that since we have in effect split up the journey into several easier journeys, the greatest characteristic velocity required is only about 15–16 km./sec. instead of the 32 km./sec. necessary for the complete Earth-Moon-Earth trip without orbital techniques.

Thus, this orbital technique seems to offer us a most useful means of achieving interplanetary travel. There are other means which may possibly be of assistance in solving the propellant problem, although they may not be so practicable as the method just mentioned. For instance, there is the Electromagnetic Launcher described by A. C. Clarke.[5]

Now, if we can prepare fuel on the Moon itself, then we shall have another means of reducing the characteristic velocity necessary for the Earth-Moon-Earth trip. In designing ships for the circular trip with landing, a characteristic velocity of 32 km./sec. is required if the rocket carries all its propellants with it and does not employ air resistance braking for the final landing on the

Earth. If refuelling on the Moon is possible, then we have instead two single trips, each requiring a characteristic velocity of about 16 km./sec. That statement is of course an over-simplification assuming that the two trips are carried out under exactly the same conditions except that one is in reverse—in practice that is not true. In the outward journey it is necessary to overcome air resistance, but on returning it should be possible to utilize it for braking, so that the characteristic velocity for the return journey might be reduced to 13 km./sec., or less. Moreover, during the outward journey the rocket would only be able to slip off one or two of its empty fuel tanks, since they would be required for refuelling at the lunar base; on the return journey they could well be shed if thought necessary. Also, the orbital refuelling technique just mentioned might be used in addition at the terrestrial end of each trip.

However, although the preparation of propellants on the Moon will facilitate travel to our satellite, it is equally clear that it does not bring any nearer the day when it will be accomplished, or render the development of orbital techniques unnecessary. The first astronauts who land on the Moon cannot go there just with empty tanks and the firm conviction that they will be able to prepare the fuel necessary to get them back safely to Earth. It will be necessary to make many voyages there and back before we can start building the lunar base, and for these voyages we shall have to use orbital techniques. The real advantage of the lunar base as far as travel between Earth and Moon is concerned is that it will enable us to improve the efficiency of the journey.

The establishment of the lunar base may nevertheless be a pre-requisite for the accomplishment of voyages to the other planets, since the characteristic velocities required for these journeys are considerably greater than that for the lunar trip. Thus, considering the two easiest journeys (to Mars and to Venus), the characteristic velocities necessary for the return trips with landings on the planets are respectively 50 and 62 km./sec. (as compared with 32 km./sec. for the lunar journey).[6] Now each of these characteristic velocities is made up of the summation of the escape velocity from Earth, the transfer to the voyage orbit, the transfer from this orbit to that of the planet concerned, and the planet's escape velocity: all this then being doubled to take the return trip into account. In each of the cases concerned the greatest individual item is the escape velocity from the Earth (11·2 km./sec.). However, since the escape velocity from the Moon is only 2·37 km./sec., if we could start our journey from the Moon instead of from the Earth we should save some 8·8 km./sec. for a single trip, and therefore about 17·5 km./sec. for the return journey to another planet. This is quite an appreciable reduction. It means that the characteristic velocity for the Moon-Mars-Moon voyage with Martian landing is only about 32 km./sec., i.e. of the same order of magnitude as the Earth-Moon-Earth trip itself.

The Moon therefore is very suitable as a spaceport for the Earth—a stepping-stone to the other planets—and it would obviously be much better and more efficient if we could prepare our fuel at our starting point on the Moon rather than cart it there from the Earth. If it should also prove possible to construct the spaceships for these planetary journeys on the Moon as well, it would be even more advantageous.

This principle—using the Moon to split up the journey to the other planets—is of course fundamentally the same as the orbital technique (preparing fuel on the Moon is an added refinement). This stepping-stone method can obviously be extended throughout the Solar System: we could use Venus as a stepping-stone to Mercury, Mars as one to Jupiter (should anyone ever want to visit these forbidding bodies) and we might be able to prepare fuel on these planets also.

Propellants to be Considered

In the space available it would be impossible to deal even cursorily with the preparation of the large numbers of propellants which have been suggested. Discussion will be restricted to the first nine elements of the periodic table and some of their compounds. These include both the most suitable propellants for chemical rockets and the most suitable working fluids for nuclear reactors. Consideration will be further confined to those materials in this group which can be used in the rocket in the liquid state (using this term broadly, to cover fluidized powders).

What are the criteria which will decide between two alternative processes for preparing a given propellant, or between the preparation of two hypothetical materials which are equivalent as far as their behaviour as a propellant is concerned? These criteria will certainly be different from those which apply on the Earth. Here, economics and politics are the two factors which determine whether a product shall be manufactured or a process operated. Economically, the manufacturing organization must pay its way; politically, well anything may happen—costs may be regulated by subsidies or duties, demand may be artificially created, supplies may be witheld, manufacture may be banned entirely. . . . In short, when setting up a factory on Earth, the first two things to do are to work out the balance sheet and to find which Government regulations do not exist or can be safely broken.

On the Moon, however, things are vastly different. There are no politicians and the only use for money is as ballast (I have only been able to think of one other use—in astronautics—for playing three-dimensional shove ha'penny whilst in free fall). Assuming that a supply of ore or raw material is available on the Moon, the questions to be asked about any process are:

(1) How much power is required to extract the fuel in the required state of purity and to liquefy or melt it if necessary?
(2) What is the gross weight of the plant required? What is the maximum weight and size of any individual item or part?
(3) What amount of labour is needed (*a*) to erect and (*b*) to operate the plant?
(4) What is the expected life of the plant?
(5) Are any harmful or beneficial by-products obtained?
(6) Are any auxiliary materials necessary to carry out the process?

These questions must be borne in mind in considering the materials just mentioned. One or two general points can be mentioned.

Many of the chemical processes carried out terrestrially are conducted in aqueous solution. This is only to be expected in view of the great abundance

of water on this planet. On the Moon, however, this could not be done. It would be necessary to conserve water supplies, either for conversion into fuel or for human consumption. This would mean that as far as possible we should avoid choosing processes which require the use of water (or other liquids) as a solvent, since conservation of water would mean the setting up of large purification units, so that it could be cyclically used.

Other processes include stages in which materials are roasted or heated in contact with air. This is also undesirable in view of the absence of an atmosphere on the Moon and the consequent necessity to conserve oxygen. We also see that heating or power generation by the combustion of our usual fuels is also excluded for this reason.

It is very desirable for us to have some rough idea of the amount of fuel it is necessary to prepare. Now at the moment it is quite impossible to estimate the total mass of propellants required to carry out the journeys between Moon and Earth (or Orbital Station) which we have in mind. The actual quantities will depend upon the design of the spaceship and the efficiency of its motors; the orbit it will follow and the method of landing; the fuel itself, etc. We can, however, get a rough estimate, and I am assuming that about 600 tonnes of each would be required per ship. For a purely atomic ship working on hydrogen, this would mean a fuel load of 600 tonnes hydrogen; for a partly atomic, partly chemical rocket it could mean a total load of 1,200 tonnes propellants. The figure of 1,200 tonnes propellants may be considered to be roughly of the right order, since it would be impossible to carry out the journeys with 12 tonnes propellant, probably impossible with 120 tonnes, whilst to our minds it would certainly be impossible for many many years to come to build a rocket which would carry 12,000 tonnes of fuel.

My first assumption, then, is that we must produce 600 tonnes of each propellant per ship. My second assumption will be that one ship per month will make the return trip. This means that 7,200 tonnes of each propellant will be required per year, or about 20 tonnes per day, or about one tonne per hour in round figures, assuming continuous operation but with allowances for plant shut-downs and hold-ups. One tonne per hour—easily said, yet a task of some magnitude when we consider that this figure relates to the pure propellant only and that we shall, in fact, have to deal with a much greater mass of the raw materials from which these propellants are prepared: if the raw materials assay only 10 per cent. of the element in which we are interested, we shall have to deal with 10 tonnes raw material per hour; if only 1 per cent., 100 tonnes per hour, and so forth. Moreover, the problem is aggravated by the fact that the elements in which we are interested are those of low atomic weight, and therefore cannot be expected to be present in the raw materials in high percentages. The figure of one tonne per hour is only a talking-point, however; such an output may not be necessary for many years after the establishment of the base.

Composition of the Moon: Selenochemistry

Much information is known about the movements and dimensions of the Moon. In addition, the topography of the face of the Moon turned towards

the Earth has been described in considerable detail and with fair accuracy; in fact much more is known about its surface than about the surface of any other body in the Solar system, except our own Earth; this is not surprising, but paradoxically, more is known about the composition of stars many millions of light years distant than about the materials of which our satellite is formed. All our information is brought to us from these bodies by light or some other type of electromagnetic radiation. This radiation bears evidence of its origin and history in various ways, but for practical purposes the most important method of gleaning chemical information from it is by spectroscopy. This can give us no information about the Moon, however, owing to the absence of any appreciable atmosphere or any incandescent place on its surface. In the optical region, the spectrum of moonlight is the same as the solar spectrum: the light has merely been reflected. No variation appears to have been reported in the other portions of the spectrum. Observation of the polarization of moonlight has been claimed to prove the existence of basaltic rock, but the evidence is scanty and rather doubtful.

In the absence of any reliable data we must be content to make assumptions concerning the composition of the Moon. The simplest assumption to make is that the composition of the Moon is mainly similar to that of the Earth, except for the absence of an atmosphere. Before adopting this, let us first consider whether this is reasonable.

Since we know nothing of the origin of the Solar System—and any theories that have been put forward *are* only theories—it is not permissible to take this assumption for granted. Even if both Earth and Moon have been formed from a common origin (for example, a jet of gaseous matter ejected from, or drawn out of, our Sun or some other star), it is still quite possible that their compositions will differ. The gaseous matter might not have been homogeneous when it broke up into the various members of our Solar System, or the processes which took place in these bodies as they coalesced, liquified, and solidified, might vary from planet to planet under the different conditions which would exist—differences in planetary mass, in distance from the sun, etc. We must therefore look for more tangible evidence concerning the composition of the various bodies of the Solar System.

Now we do get direct evidence concerning some of these bodies—the Meteorites, most of which are part of our Solar System, others coming from outer space. The larger ones penetrate our atmosphere and reach the ground; it is true that they are raised to incandescence as they pass through the atmosphere (due to the air resistance), but except for the very small ones, only a thin skin is affected by this treatment; the low thermal conductivity of the material and the rapidity of the descent ensures that most of the centre remains unchanged. Many analyses of them have been made and considerable variations in composition are found, there being every gradation between the two main types—metallic and stony.[7] The metallic meteorites usually consist of iron-nickel alloys, and predominate; the stony type includes a wide variety of rocks, mainly basaltic in character. Often these do not correspond to any of the minerals found on our Earth; thus some meteorites contain calcium sulphide or iron nickel phosphide. The nature of the stony and metallic meteorites and

the proportions in which they occur has been put forward as evidence in support of the former theory that the Earth consists of a large core of iron-nickel alloy surrounded by a shell of rock. However, the evidence of the meteorites cannot be considered of much use to us in deciding the composition of the Moon; it is difficult to extrapolate from a few tons up to a mass of over 70 trillion tons. Moreover, even those meteorites which are part of our Solar System might have originally have been captured from outer space. The best we can say is that the analyses of the meteorites show that they consist of the same chemical elements as are found on our Earth.

There is another method by which we can seek evidence—by comparing the densities of the planets. These are:

Mercury	Venus	Earth	Moon	Mars	Jupiter	Saturn	Uranus	Neptune	Pluto
5·6	5·1	5·52	3·3	3·9	1·4	0·7	1·3	1·3	?

We see that these differ greatly, and we might consider that this is evidence that the planets themselves differ greatly in composition. I have calculated the mean density of the planetary system from the relation (sum of masses)/(sum of volumes), neglecting the variations in temperatures. The figure obtained is 1·12, but that only indicates the concentration of available matter in the four giant planets.

It would be wrong to use these density figures to estimate the compositions of all the planets. Firstly, I have my suspicion concerning the figures for planets perpetually sheathed in clouds, such as Venus or Jupiter. It is probable that the diameter of the planet itself is appreciably less than the diameter of the atmospheric skin actually measured; the true volume of such planets would therefore be less than the published figures and consequently the densities given above would have to be increased. Secondly, as the size of a planet increases so also does the magnitude of the pressure at its centre, and at the pressures that must exist inside the larger planets, matter will be highly compressed and therefore of greater density than we are accustomed to. Taking this into consideration, Goldschmidt's classical conception of the segregation of the Earth's constituents into three zones (the innermost core being of iron-nickel) is not necessary to explain the density of the Earth. According to modern views[8] the core of the Earth really consists of practically unaltered solar material and may contain 30 per cent. hydrogen.

Now if we were to postulate that all the planets are composed of the same material on the macro scale, then since the compression and hence the virtual density of this material will be greater in a large planet than in a small, we should expect the observed densities of the giant planets to be greater than those of the small ones. Instead we see that they are exactly the reverse, even if we make generous allowances for errors in estimating volumes. Clearly there are large variations in composition throughout our planetary system, and this applies not merely to the differences between the giant planets and the small ones, but also between the individual members of the latter group. We see that the

densities of Mercury, Venus and the Earth are all about 5–5·5, whereas those of the Moon and Mars are between 3 and 4.

This indicates that the assumption that the Moon's composition is similar to that of the Earth rests on shaky grounds, but fortunately for our purposes the difference is in the right direction, i.e. the Moon's density is less than that of the Earth, so that we may expect the lighter elements in which we are interested to be even more abundant on the Moon than they are here.

But in considering planetary densities we only consider part of the question. The densities given refer to the *whole* bulk of the planet, but for our purposes we are only interested in that portion of it which we can reach, i.e. the outermost part of the surface crust. Even on the Earth, with all our technical resources at hand, we have no direct information about any part of the Earth's interior deeper than about four miles. In point of fact, the greatest depth reached was in an oil well—20,521 ft., and then they didn't find any oil! We had better therefore turn our attention to the surface and immediately underlying layers, bearing in mind the modern geochemical theories. Goldschmidt's conception mentioned earlier envisaged the condensation of the solar gas into molten zones or phases, the various elements being concentrated preferentially into one or two of these phases according to their nature. The outermost zone (the lithophil) contained siliceous compounds; and that was surrounded by the atmosphere (atmophil) of uncondensed gases. Later, the outermost zone began to crystallize fractionally, forming a crust of igneous rocks. These consisted mainly of silicates since they were formed from the lithophil, but the elements which were the main constituents of the deeper zone were not entirely absent from these igneous rocks, since there would be a certain amount of mutual solubility. The modern theories are only concerned with the abundance of elements in the earth as a whole, and do not conflict with Goldschmidt's ideas concerning the lithophil.

Now as far as we know the Moon has also been formed by the condensation of gaseous material. In that case we would expect its original crust to have formed in much the same manner as that of the Earth, and to contain the same or an even greater preponderance of the lithophil elements, which include the nine in which we are interested as propellants. The rocks in which they occur, however, may be quite different to those found terrestrially.

Geologists divide terrestrial rocks into three main groups: *igneous* (those formed by solidification of the magma, or molten rock), *sedimentary* (formed by the weathering of igneous or metamorphic rocks), and *metamorphic* (formed by the action of pressure and heat on igneous or sedimentary). The igneous rocks were the primary formation, having crystallized from the parent magma, but they did not possess a uniform composition, since segregation took place. The enrichments which took place during the initial and main crystallizations are of little importance but the final crystallization is of great economic significance. Concentration of elements also took place during the later changes which modified the primary igneous rocks—particularly during the weathering processes and by biological action.

Now in the light of our present knowledge, it is unlikely that any significant deposits of sedimentary rocks exist on the Moon, since its atmosphere (if any)

has long since disappeared. Metamorphic rocks will also be scarce, and it is unlikely that living organisms (if they ever existed there) could have accomplished any measurable concentration of elements. We must therefore seek our propellants from igneous rocks alone, and have to examine whether the elements in which we are interested will be widely distributed throughout the crust or will be concentrated into sources which can be worked more economically.

Now it was mentioned above that the significant enrichment in igneous rocks is that which takes place during the final crystallization. The products formed during this stage are termed pegmatites or pegmatic veins. As the molten magma gradually cools, the most refractory elements tend to separate first and form the crust. The compounds of the lighter elements in which we are interested are comparatively low-melting, and moreover they strongly depress the freezing point when mixed with other minerals. They therefore remain fluid in the pegmatic veins between the solidified masses. This residual magma would in fact contain salts of lithium and sodium, fluorides and chlorides, boron, minerals rich in water of crystallization, volatile compounds of tin, etc. It becomes enriched as silicates separate from it and finally solidifies to form the pegmatites we find to-day. The magma in the pegmatic veins becomes very fluid (partly due to the increase in water content) and this encourages the formation of very large crystals. These pegmatites are often the main source on the Earth of some of the lighter elements.

It therefore seems that on the Moon we shall find workable deposits of some of the elements in which we are interested, and it may well be that they will be concentrated into pegmatites, although the minerals found may not necessarily be the same as those found on the Earth. On the evidence of the density of the Moon it is possible that they will be more abundant there than they are on the Earth. More abundant, that is, as regards *distribution*; it must not be forgotten that the Moon is smaller than the Earth. Its diameter is only 0·27227 that of the Earth, so that its total surface area is about 7·4 per cent. of that of the Earth. Only 28·3 per cent. of the Earth's surface is land, as compared with 100 per cent. for the Moon. The available area on the Moon is therefore only about 26 per cent. of that on the Earth, so that the *total* amount of useful ores available may well be less than on the Earth.

It is now necessary to consider some of the individual propellants, their possible sources, and processes which might be used to extract them. They will be dealt with in the order of increasing atomic weight.

Hydrogen

Terrestrially, hydrogen is found in the free state, in living matter, in hydrides and in water. Although living matter might be a source of hydrogen on a planet such as Mars, it is improbable that any such organisms exist, or have ever existed, on the Moon. We can therefore omit it from consideration—and we can also rule out coal, oil, etc., since these are formed by the metamorphosis of animal or vegetable material.

Whilst the Moon has a negligible atmosphere it may not be beyond the bounds of possibility that gases are still imprisoned beneath its surface or still

being evolved from these sub-lunar depths. Hydrogen could, for instance, have been set free on the solidification of the parent magma but imprisoned beneath the crust, later to seep through cracks and fissures, or it might arise as a by-product of a nuclear reaction; nowadays, it is thought that volcanic action may be due to the heat liberated during the radioactive decay of subterranean materials. If there is such a source of hydrogen on the Moon, it will be comparatively easy to utilize it. It would merely be necessary to tap it and pipe it to the purification and liquifying plant. It is unlikely that many natural gas hydrogen wells exist on the Moon, but it is quite on the cards that some underground supplies will be found when we start lunar drilling.

Rocks containing occluded hydrogen are almost certainly present on the Moon: they are well known on the Earth and most meteorites contain hydrogen and other gases. At first thought this might seem quite a possible source of hydrogen. The plant required would be relatively simple—the process used would involve size reduction of the ore (crushing, grinding, etc.), heating the powder to a moderate temperature to expel the hydrogen, which would then be pumped off, purified, and liquified, whilst the spent ore was rejected after passage through a heat exchanger. However, further consideration shows that the proposal is probably impracticable: figures quoted for the occluded hydrogen in meteors and terrestrial rocks range from 0·2–140 c.c. gaseous hydrogen per 100 g. rock, some nitrogen, carbon dioxide, etc., also being present. We may take the range 1–100 c.c. hydrogen/g. rock as a favourable estimate. This corresponds to 0·009–0·9 per cent. hydrogen by weight, so that to produce the required tonne per hour it would be necessary to process 110–11,000 tonnes rock per hour. Judging by the terrestrial sources it is more likely to be the greater figure than the lesser that we would have to deal with, but even if we settle for 100 tonnes per hour we find that the difficulties are considerable. This quantity of ore can be dealt with in commercial grinding machinery (such as a ball mill), it can probably be heated, but it is doubtful whether it could be mined, unless present as a deposit of powder or small lumps, or in a cliff face.

Of the forms in which hydrogen occurs terrestrially, there remains water to be considered. Long ago of course, it was thought that seas were present on the Moon—hence the word Mare on the lunar maps. This was later found to be incorrect. However, it would be equally incorrect to rush to the opposite point of view and state that because there are no seas there can be no water at all on the Moon. The only practical evidence for the absence of water that could exist would be spectrographic and would be only negative evidence. Theoretically, it might be thought that owing to the near-vacuum existing at the lunar surface any water that might once have existed would long since have evaporated and been lost.

Presumably the water would be lost gradually by loss of individual molecules which attained the escape velocity from the Moon (2·37 km./sec.) and which did not collide with other molecules or the lunar surface. But the vapour pressure of a substance provides a rough indication of the velocity of its molecules, and the vapour pressure of water falls off rapidly with temperature, and is practically negligible below −40° C. (233° K.). On the other hand, the absence of an atmosphere means that collisions with other molecules are much

less likely, and the low escape velocity for the Moon means that it is easier for water to escape there than it is on the Earth at the same temperature. Moreover the velocity mentioned is only a mean velocity; actual velocities will be statistically distributed around this, so that some molecules will always attain escape velocity whatever the conditions and a gradual loss of water is to be expected. 'But whether enough time has yet elapsed for all the water to have been removed from the lunar surface is quite problematical.

The mean temperature of the Moon's surface varies between 200 and 300° K. whilst that of the interior is perhaps 230° K. This means that if the lunar surface were uniformly smooth any water that might exist on the surface would alternately melt and freeze as lunar day and night succeeded each other. The maximum temperature may be sufficient for an ice-field a few feet in depth to melt completely during the course of the day, since the lunar day is about 14 times as long as ours—in normal latitudes of course (our polar days are several months in length). The vapour pressure at the maximum temperature (30° C.) is appreciable, so that over the course of thousands of years this surface water would disappear. For a shady spot, however, the temperature would not rise above freezing point and might even be below −40° C. The vapour pressure of ice at this temperature is quite low so it is likely that ice deposits might be present on the Moon in caves, crevasses, underground caverns, etc.

Moreover, water would almost certainly be present in the sub-surface rock. Despite its low-boiling point, water is quite soluble in the molten magma, particularly at the pressures that would have existed under the surfaces of the solidifying rock. It tends to remain in the residual melt as the silicates crystallize out, and the magma in fact becomes a semi-aqueous solution, although still at a temperature of some hundreds of degrees C. When final solidification takes place, the water stays in the rock, particularly in the pegmatites. We therefore find that the sub-surface igneous rocks may be richer in water than the surface minerals; they may in fact contain as much as 5 per cent.

Water is therefore a second possible source of hydrogen on the Moon; it is also one of the most suitable sources from the astronaut's point of view, since it provides a supply of oxygen as well. Moreover water itself might be used as a working fluid for atomic rockets. Should it be necessary to prepare hydrogen from water, however, the most suitable method would be electrolysis. Electrolysis wastes neither material nor energy: all the water is utilized, since oxygen (the only other product) is also required at the base; the process is extremely efficient. Little labour is required to operate the cells, and they have a long life. To produce 1 tonne hydrogen per hour (together with 8 tonnes oxygen) a power supply of about 50,000 kW. would be necessary; the cells themselves might weigh 5,000 tonnes.

Having separated the hydrogen it is necessary to liquefy it; this may be accomplished by the Linde-Hampson Method. Descriptions of this will be found in Thorpe's Dictionary of Applied Chemistry. It is difficult at this stage to assess the requirements of the liquefaction process, since present-day plants are for research work and have a comparatively small output. Thus the plant at the Clarendon Laboratory, Oxford (installed 1946) produces 13 l./hr.[9] For

the quantity of hydrogen under consideration, 25,000 kW. would probably be necessary. This would represent the total power required if underground reservoirs of hydrogen were utilized; for the electrolytic production of hydrogen and oxygen, for liquefaction of all the hydrogen and part of the oxygen, and for miscellaneous purposes about the plant, the total requirements might well amount to 100 MW.

Deuterium

This has been put forward as a possible propellant for atomic rockets, its greater density in the liquid state giving it some advantage over hydrogen for storage purposes. The difficulties of separating or preparing deuterium are too great, however, for us to consider its production at the lunar base.

Helium

On the Earth, helium occurs in volcanic gases, in natural gas, and occluded in rocks; if it occurs at all on the Moon, it will be in one or other of these forms. It is most unlikely that any active volcanoes or fumaroles still exist on the Moon, but it is yet possible that subterranean reservoirs of helium exist; they might be formed as the result of radioactive decay. If we can tap them by drilling where the geological formation indicates their possible existence then it will only be necessary to liquefy the gas. Whether these reservoirs would contain sufficient helium to meet our needs is another matter.

Occluded helium will almost certainly be present in some minerals. It could be extracted by the same method as that suggested above for separating occluded hydrogen, but again the materials balance shows that this is not a very suitable source. The richest ores known are thorianite and uraninite (of which pitchblende is a particular variety), which contain up to 0·19 per cent. and 0·15 per cent. helium respectively. This means that even in the best case about 670 tonnes ore will have to be handled to obtain 1 tonne helium. However, should such minerals exist on the Moon, no doubt in due course some method would be devised for extracting the uranium or thorium in them for use in nuclear reactors. In that case, it would obviously be useful to collect the helium which would be set free as a by-product.

The utilization of subterranean deposits of the gas therefore seems to be the most promising source of helium; moreover, after tapping these deposits, only purification (by freezing out contaminants) and liquefaction are necessary. However, the liquefaction of helium is more difficult than the production of liquid hydrogen, and it was in fact the last of the common gases to be liquefied. The difficulties arise from two causes: firstly, its critical temperature is very low (−268° C. or 5·1° K., the critical pressure being 2·3 atmospheres); secondly, the Joule-Thompson inversion temperature is also low (−240° C. or 33° K.), so that the Linde-Hampson method used for liquefying hydrogen will here only be of use in the very last stages of the cooling process. Nevertheless, helium was originally liquefied by this method, after first being cooled to −253° C. by the Cascade Process. The alternative method is due to Kapitza[10]; the gas is made to cool itself by operating an expansion engine.

There is little data published which would enable us to compare the

potentialities of these two methods for use in a lunar plant of the size we are considering. In view of its comparative simplicity Kapitza's method has advantages, but much development work will have to be done before large-scale production becomes possible, e.g. the expansion engine would require considerable modification. In view of Kapitza's present position in the U.S.S.R., this development work may well be taking place now.

Hydrogen versus Helium

Although the data is scanty, nevertheless it is possible to make some comparison of the advantages and disadvantages attendant on their production at the lunar base:

(1) The likelihood of finding a source of the element is somewhat greater for hydrogen than for helium, but the probability of finding a reservoir of the *free* gas should be greater in the case of helium, in view of its inertness.

(2) If it proves necessary to extract hydrogen from water, then the production of liquid hydrogen would require the expenditure of much more energy than the mere liquefaction of helium. However, if both hydrogen and helium were found in the elemental form, the power requirements for their liquefaction are of the same order of magnitude, rather more energy being required for helium.

(3) Both elements are on a par as regards the use of auxiliary cooling agents in their liquefaction; the helium liquefier, however, has moving parts.

(4) Hydrogen can be used in both atomic and chemical motors; helium, being inert, cannot act as a chemical propellant. It might, however, be used as a diluent in chemical motors, to prevent excessive chamber temperatures whilst reducing the mean molecular weight of the exhaust gases. This means that if it was found necessary or desirable to run ships on helium and prepare it at the base, it would still be necessary to prepare a small quantity of chemical fuels (or to transport them from the Earth).

(5) Although liquid hydrogen will be safer to handle on the Moon than it is here (in view of the absence of an atmosphere), liquid helium will still be the easier to deal with. There is no ortho/para equilibrium, neither does helium solidify so readily. This would lessen the danger of blockages in pipelines, pumps, etc. Helium is peculiar in that it does not solidify at any temperature unless under a pressure of at least 25 atmospheres.

Lithium

The lightest metal, lithium, melts at 186° C., a temperature low enough for it to be stored in the rocket in the molten state and used as a liquid propellant. Whether it will ever prove possible to construct a combustion chamber that will prove suitable for use with lithium is another matter. Lithium is a very reactive substance, and at the temperature of the chamber would certainly cause rapid disintegration of most materials, metallic or non-metallic. The molten metal could, however, be stored in containers of iron, stainless steel, molybdenum or Inconel. Although the development of lithium-powered rockets may seem much further off than the utilization of hydrogen or helium, it is nevertheless worth considering the lunar production of the metal.

On the Earth it is widely distributed, but in small quantities, usually being found as silicates and phosphates, sometimes as fluorides or chlorides.[11] Because of its low atomic weight (6·94), even rich ore does not contain a high proportion of the metal (2·5–4·5 per cent. is usual). These deposits usually occur in the pegmatites mentioned above; large crystals are frequently found. Thus, one crystal of Spodumene mined was 42 feet long and was estimated to weigh about 65 tons. It is quite probable that the lunar surface will have a greater lithium content than that of our Earth, and if it has also been concentrated into pegmatites and has separated as large crystals, then it will not be too difficult to mine with the aid of simple equipment. A greater abundance of lithium might go hand-in-hand with a greater diversity of ores; these might include richer materials than are found terrestrially, materials such as lithium fluoride (LiF, 25·7 per cent. Li) or chloride (LiCl, 16·4 per cent. Li).

These halides would in fact be the most suitable source of lithium, since it is prepared by the electrolysis of molten salt mixtures. With other ores it would be necessary to use a complicated process to concentrate the lithium and to convert it into the chloride, e.g. the U.S. Bureau of Mines[12] has developed a process in which Spodumene is heated with a mixture of calcium sulphate and carbonate, and the product treated with calcium chloride solution. This would be too complicated for operation at the lunar base, since it would involve additional mining (of gypsum and limestone), recovery of the water, and probably also some cyclic process for taking the chlorine set free in the electrolytic cells and re-forming calcium chloride. We must therefore hope that fluoride or chloride ores will be available, should it prove necessary to prepare lithium.

Extraction of lithium is at present carried out by electrolysis of a mixture of the chloride and potassium chloride (the Guntz process).[13,14] The potassium salt remains practically unchanged, but greatly facilitates the electrolysis and lowers the melting point of the melt (the cell is operated at about 400° C.). Over 95 per cent. of the lithium is recovered, 1 kg. being produced for an expenditure of 9 kg. lithium chloride, 0·4 kg. potassium chloride and 66 kWh. The production of the required tonne/hour would therefore require 66 MW and the mining of 9 tonne lithium chloride/hour. The chlorine liberated in the cell would also have to be liquified if it were proposed to utilize it as a propellant; if not, it would have to be disposed of or stored.

It would of course be better if we could use the fluoride for producing lithium, since lithium and fluorine would provide a more powerful propellant combination for chemical steps. There are difficulties in electrolyzing the fluoride, and very little work has been done to investigate this possibility.

The only possible alternative to electrolysis is the Kroll process[15]; a mixture of lithium and calcium oxides is heated with aluminium *in vacuo*. This is at present in the laboratory stage, but it might possibly be developed for use on the Moon; the aluminium could be derived from the structures, tanks, etc. jettisoned by spaceships.

Beryllium

The metal beryllium melts at about 1,285° C., so that if it were to be used as a propellant it would have to be in the form of a fluidized powder. However,

its extraction is difficult (it has been described as "the world's No. 1 metallurgical headache"). The various methods which have been suggested or investigated are reviewed elsewhere[16,17,18] and will not be detailed here. We may merely note in passing that the most promising method for lunar operation would be the electrolysis of fused halides, particularly if these occur naturally on the Moon.

Boron and Boron Hydrides

Boron itself is a very refractory material and is difficult to prepare. However, boron forms many volatile hydrides, which are potentially important as rocket fuels, indeed the use of diborane, B_2H_6, as a propellant (in conjunction with oxygen) was recently reported. We must therefore examine the possibility of preparing these hydrides at the lunar base. The first stages in their manufacture[19] would be the isolation of pure boron oxide and its conversion to magnesium boride by heating with magnesium powder in the absence of air. The mixture obtained would then be decomposed by adding it to acid, in the absence of air since the crude gas set free may contain traces of silicon hydrides, which are spontaneously inflammable. On the Moon, of course, this fire hazard would not exist, and we might even find a deposit of magnesium boride. Nevertheless, the fact that all the hydrogen contained in the hydrides we produced would be derived from acids (which we should either have to transport to the Moon or manufacture there laboriously) clearly renders this process impracticable. In addition to this, the gas obtained is a mixture of various hydrides which must be purified and separated.

Carbon

Most of the terrestrial fuels are compounds of carbon; as mentioned above, they are also mostly of biological origin and are not likely to occur on our satellite. They cannot be ruled out entirely, however, since small amounts of solid hydrocarbons have been found in meteorites. If similar compounds were found in lunar rocks, it is just feasible that it might be possible to seperate them by solvent extraction and distillation, then cracking them to give the required light petroleum oil, but this would be by no means as easy to do as some of the processes already dealt with.

These hydrocarbons have probably originated as the result of the action of water on certain carbides, and it might be suggested that this offers a means of preparing organic propellants such as methane, ethane, etc. However, it is unlikely that any deposits of carbides would exist on the lunar surface, although iron carbide, etc., might occur in the deep interior. Moreover, would it not be better to utilize the available lunar water resources by converting them into hydrogen and oxygen rather than into hydrocarbons by reaction with any carbides that might be found? The production of hydrocarbons would mean that the oxygen of the water would be bound up in the comparatively useless iron oxide.

Nitrogen and Ammonia

We now come to gaseous elements again. The first of these, nitrogen, is of course unsuitable for use as a propellant: in chemical motors, because of its

comparative inertness; in nuclear motors, because of its high atomic weight. Any lunar production of nitrogen would be for the purposes of producing synthetic air, or for some auxillary process.

However nitrogen does form a few hydrides which are potential rocket propellants. These include ammonia, NH_3, which has been suggested for use as a working fluid in atomic rockets, and hydrazine, N_2H_4, which could be used in the chemical step. Ammonia is known to exist in the atmospheres (and probably also in the outer shells) of the giant planets of the solar system; indeed, it has been suggested that these planets are ideal "filling stations" for atomic rockets. Unfortunately, we cannot proceed to the inference that ammonia will also be present on the Moon, for the following reasons:

(1) It is known that elements of odd atomic number are much less abundant than neighbouring elements of even atomic number. Thus, on the Earth, nitrogen (At. No. 7) is much less abundant than either carbon or oxygen (At. Nos. 6 and 8, respectively). It is unlikely that this is a purely terrestrial phenomenon; it is probably connected with the degree of stability of the nuclear structure. The apparent profusion of ammonia on the giant planets does not contradict this statement, for the ammonia is accompanied by a considerable amount of methane and ice (i.e. the corresponding carbon and oxygen compounds), in addition to the enormous rocky cores. The abundance of these three compounds may in part be ascribed to the low temperature and high surface gravitation of these planets.

(2) Nitrogen is a comparatively inert element, and would tend to remain in the elemental state while more active elements (such as carbon, oxygen, and most metals) would combine with one another. The gaseous nitrogen would be expelled from the cooling magma and would be lost from the Moon with the gradual loss of its atmosphere.

(3) On the Earth the available nitrogen has been concentrated through the operation of the "nitrogen cycle," i.e. by combination of the nitrogen and oxygen of the Earth's atmosphere during lightning discharges followed by biological utilization of the products of the reaction. Neither of these processes takes place on the Moon.

Taking these considerations into account, it is seen that it is unlikely that large amounts of nitrogen or its compounds will occur on the Moon; a small quantity of ammonium salts may be found. These would have been formed by volcanic, not biological, action.

If ammonium salts do exist on the Moon, it will be possible to prepare ammonia by heating them. To obtain hydrazine, the ammonia would then have to be oxidized with sodium hypochlorite, a compound which is of course not readily procurable there. It therefore seems that whilst it may be possible to prepare a small quantity of ammonia, it would not be practicable to convert it to hydrazine.

Oxygen

The Moon has no air, but as we have seen above it may well be possible for us to prepare oxygen as well as hydrogen by electrolysis of water. Oxygen will also be present in the rocks in considerable amounts, so that it is necessary

to consider whether it is possible to extract it from mineral sources. The compounds concerned would be either (*a*) oxides or hydrated oxides, or (*b*) oxy-salts, and the possible methods of extraction are (i) heating, and (ii) treatment with water or acids. The second process would be impracticable for lunar operation, but even if it were not it could be ruled out, since the oxygen-bearing substances used are not likely to be found on the Moon—they are chiefly products of the laboratory. The materials which in all probability will be found are oxy-salts such as silicates, phosphates, carbonates, borosilicates, etc., i.e. materials from which it is difficult to extract oxygen. However, it may be that deposits of some of the higher metallic oxides from which oxygen is evolved on heating (such as manganese dioxide) are present, and if only a small amount of oxygen is required this method would be suitable. This would be the case if an atomic ship capable of running on hydrogen or helium had been developed, and sub-lunar reservoirs of these gases were located, for then oxygen would only be required for physiological purposes and for small chemical steps.

Ozone

To increase the exhaust velocity ozone, O_3, may be used as the oxidant in place of oxygen, O_2. Methods for the preparation of ozone for oxygen are essentially based on the conversion of electrical or thermal energy into chemical energy; that commonly used industrially is the exposure of oxygen to the action of a silent electrical discharge. It is found that the efficiency of the conversion increases with drop in temperature; if the ozonizer be cooled to liquid nitrogen temperature, a 99 per cent. conversion can be obtained. Theoretically, 1·2 kg. of ozone is formed per kWh., but in practice the yield is much less. On this basis, however, about 6·7 MW electricity would be required for converting ***all*** the oxygen produced by the electrolyzer mentioned when dealing with hydrogen (i.e. 8 tonnes oxygen/hour) into gaseous ozone. Since an atomic, rather than chemical, rocket is envisaged as necessary for the trip, much less than this amount would be required for any chemical steps. Nevertheless, careful consideration would have to be given to whether the advantages (if realizable) of using ozone instead of oxygen outweighed the disadvantages of the extra power and plant required. There might be added danger in using ozone, for whilst the pure liquid is said to be stable, if contaminated with liquid oxygen it is sensitive to mechanical shock.

Fluorine

It is not possible at the moment to make even the haziest predictions concerning the possible production of fluorine. Although much progress has been made during the last ten years, the fluorine industry is but in its infancy. Present-day manufacture is by electrolysis,[20,21] usually of a mixture of potassium fluoride and hydrofluoric acid, the latter being the consumable constituent. It is unlikely that this acid would be prepared on the Moon, although fluorides are probably present. We can only hope that over the next few years a more suitable process may be developed, e.g. the electrolysis of fused lithium fluoride.

Power Generation

It is evident from the previous discussion that considerable amounts of

energy would be required to operate the plant for manufacturing propellants—the figure of 100 MW was mentioned in connection with the production of liquid hydrogen and oxygen from water. This corresponds to the output of a fair-sized power station on the Earth, yet the methods of generating power which are conventional here cannot be utilized on the Moon. Alternative ways will therefore have to be sought; some of the more obvious ones are the following:

(i) *Batteries* (i.e. utilization of chemical energy). These are incapable of supplying the amount of energy we require, but even if our demands were far, far less, they would be impracticable since the amount of energy expended in their construction would be less than that they delivered.

(ii) *Photocells or Thermocouples.* These might be suggested as sources of lunar power, since they have the apparent advantage of converting the radiant energy received from the Sun directly into electrical energy. Unfortunately, only a small current is produced by each unit, so that an astronomical number would be required to generate 100 MW. It would in fact be impossible to construct or operate even a much smaller array of cells or couples.

(iii) *Nuclear Energy.* By the time that a nuclear-powered rocket has been developed, no doubt the harnessing of nuclear energy to the generation of electrical power will also have been achieved. This may well prove the most suitable method, but many problems will have to be solved first. In particular, there will be the question of the disposal of radioactive waste products.

(iv) *Utilization of Solar Energy.* This can be done by more efficient methods than the use of thermocouples or photocells, and the quantity of energy available is considerable: about 2 cal./cm.^{2}/min. falls on a surface perpendicular to the sun's rays, so that an area of 0·072 km.^{2} (about 18 acres) receives energy at the rate of 100 MW. Owing to the rotation of the Moon on its axis, the rays would not remain perpendicular to the Moon's surface for long, so that any installation operating at the *mean* rate of 100 MW would need a "catchment area" much larger than 18 acres. Nevertheless, there are great possibilities in this suggestion; the sun's rays would be focussed by means of mirrors, either for the production of a very high temperature (the "solar furnace"), or for heating a boiler for power generation. The mirrors would be kept trained on the sun by an automatic mechanism. A considerable amount of work is going on at the moment to develop such devices, particularly that being carried out by the Centre National de la Recherche Scientifique.[22]

The great disadvantage of this method of obtaining energy is that the power output is variable, and is in fact zero for a great part of the time (at night). It would be desirable to have some method of storing energy, for use during the long lunar night (about 14 terrestrial days). The principle of the steam accumulator could be utilized, or the energy might be stored as the latent heat of fusion of some high-melting substance. Still, on the Moon there can at least be no interruptions due to bad weather, whilst the much longer day means that starting-up and stopping losses will be less.

The amount of solar energy received is so large, and the conditions on the Moon are so favourable for its utilization that it is inevitable that some form of solar power plant will be developed there eventually, even if not previously adopted

on the Earth. Initially, however, it may well be necessary for the lunar base to be powered by nuclear energy.

Plant and Equipment

In desjgning plant for operation on the Moon, it will be necessary to bear in mind the changed conditions that will be encountered there, in particular the smaller gravitational force. To quote only two effects resulting from this: drop-hammers, stamps, or gravity-operated presses will be practically ineffective; precipitates or suspensions will take a much longer time to settle. Many such considerations could be discussed, but will have to be deferred to another time.

No mention has yet been made of any provision for storing the fuel that is prepared. The simplest solution is to pump it directly into the fuel tanks of spaceships at the base (for there will always be several ships there—ships that have brought the staff or plant to the Moon). In this connection it should be noted that it is highly desirable that the Earth-Moon rockets should be run on the same propellants as it is feasible to prepare on the Moon. This would avoid the necessity of cleaning out the tanks before filling them at the Moon and prevent mishaps due to the mixing of two propellants or to the failure of the tank material in contact with a propellant for which it was never intended.

It is the tendency nowadays to leave as much chemical plant in the open as possible, and most of the lunar plant would not be housed in any building. The absence of atmosphere, and hence weather, would minimize corrosion problems, although it might be necessary to shield some parts of the plant (particularly the liquefaction section) from the Sun. Buildings for the staff would have to be erected, and these would probably be pre-fabricated. They would have to be gas-tight and fitted with air-locks, so that some relief could be obtained from the tedium of having to wear space-suits. Traditional building materials would be unsuitable; metal would be preferable. Probably a near-cylindrical shape (resembling that of the Nissen hut) would be best, and it might well be possible to construct the buildings from spaceship hulls.

Physiological Requirements

In addition to the erection of buildings other provision must be made for the welfare of the lunar staff. Food would have to be brought from the Earth, but as indicated above, a supply of water might be made available and could be purified for drinking purposes. It might be necessary to dispense with the luxury of washing, however.

All buildings would have to be air conditioned; methods of replenishing or treating the air in spacesuits and rocket cabins have already been discussed in the literature. The processes described have usually involved separation of carbon dioxide and water (the respiration products) but have not converted them into any particularly useful product. With the possibility of erecting larger plant at the lunar base, more ambitious schemes may be considered. The carbon dioxide could be separated from the air by cooling, vaporized

again, mixed with hydrogen produced at the lunar plant and passed over a catalyst to produce alcohols or various other organic chemicals, which would have many uses on the Moon.

Since the base would be occupied continually, plant for disposing of the other body waste products would have to be installed. It would be neither desirable nor economic merely to dump this waste into cesspools; there would probably be no bacterial activity to render it innocuous. The best course would be to vacuum-distil off the water (for utilization in the propellant plant) and store the dry residue for possible use subsequently. Being rich in nitrogenous material, this residue might later be used for preparing explosives or other chemicals, or might be used as fertilizer should it ever prove possible for experiments in growing plants on the Moon to be begun.

Establishment of the Base

I have talked facilely of the base and its operation—a matter requiring a high degree of technical skill. It is necessary also to consider the initial establishment of the base—a much more difficult matter, comparable not merely to an Everest expedition, but rather to the Normandy invasion as far as the expenditure of effort and ingenuity is concerned.

After suitable raw materials have been discovered on the Moon, what will the actual establishment of the base entail, and how can it best be carried out? Stated simply, it involves the transport from the Earth of several thousand tons of plant, its erection and operation—a simple statement, but what a wealth of detail it covers. First, a suitable site for the base must be selected—a site within easy distance of the ores if possible, yet provided with a fair expanse of level ground. This will be necessary so that plant and buildings can be erected without having to do too much preparation. It will also be necessary so that part of it can be utilized as a rocket-port; the plant ought to be landed on the site of the base to save having to transport it a considerable distance over the lunar surface. This is not merely a question of distance as such, although we do well to remember that whilst we think of the Moon as a small body compared with the Earth the distances are still considerable, its circumference measuring over 6,700 miles. We have to remember that some lunar mountains equal those of the Earth in height, that they are much more numerous and more rugged, and that in general the lunar surface is much more forbidding than ours, since it has not been weathered.

For similar reasons, when propellant production has begun and the shuttle service is in operation it will be desirable to land the spaceships as near the plant as practicable. Once the site has been chosen and surveyed, an advance party will be sent there; they will have the task of supervising the pilotage and landing of unmanned cargo rockets carrying the plant. I make the suggestion of using unmanned rockets because the amount of material to be transported from the Earth is such that it will involve not five or six but a considerable number of rocket-trips. The simplest method of carrying this out is to use single-trip unmanned rockets. This will involve the loss and wastage of these rockets from the terrestrial point of view, but it will involve neither risk to life nor the trouble of having to train a large number of pilots and having to

return them to the Earth, whilst from the lunar point of view these rockets would not be waste or scrap material—they would be an invaluable source of raw material and spare parts for the repair of rockets, construction of plant, buildings, etc. Any fuel remaining in their tanks could be collected and stored for future use. The fact that they were only required to make the journey one way would enable them to carry a higher pay-load; so would the absence of a crew, since apart from the saving in weight due to their own mass, equipment such as air conditioners, bunks, food supplies, etc., could be dispensed with.

I have just mentioned the use of the bodies of these rockets for constructional purposes on the Moon, a procedure that has been termed cannibilization. I cannot stress the importance of this too much. The materials and equipment forming these rockets could not possibly be manufactured on the Moon for a long, long time afterwards; moreover, a considerable amount of energy will have been expended to take it to the Moon, where it is of great use. It would seem silly to expend as great an amount to take it back to the Earth, where it is commonplace. It would indeed be an advantage if both before and after the establishment of the lunar base each circular trip rocket could deposit on the Moon as much of its equipment as possible before it returned to Earth.

For both the cargo rockets and for the space ships making the round trip from and to Earth it will be necessary for us to have devised control equipment to enable us to make pinpoint landings on the site. No doubt we can employ some form of radar device, partly operated by the lunar advance party, partly by automatic means. The landing technique itself will be developed before we even attempt to travel to the Moon—landing research can be carried out on the Earth itself.

Much research will of course have to be done before it will be possible to establish the base; research on all aspects of the project, including the propellant process. It may prove necessary to investigate methods which would never otherwise be studied, merely because they would be uneconomic here; on the Moon they may be the only possibilities open to us.

Conclusion

This has been mainly a preliminary survey of the possibilities and problems of the Lunar Base; for convenience, attention was directed to a specific task, viz. the provision of 600 tonnes of propellant each month for refuelling a space-ship returning to Earth. It was shown that this is likely to be an operation of considerable magnitude; in fact it may well be impossible or undesirable to begin with production on such a scale: we might aim at refuelling only one ship per year or we might merely build up a reserve store of propellants. It is to be hoped that at a later date it may prove possible to deal with the many aspects of the subject which either were not referred to, or were dismissed in a few words. For the Lunar Base is important as a long-term project: it will be of great assistance to us when we wish to travel beyond the Moon to the other planets; it is the first step towards our ultimate aim of Interplanetary Colonization.

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SOME PROBLEMS OF INTERPLANETARY NAVIGATION

A Review by D. J. CASHMORE, B.Sc.

On April 21, 1950, two papers were read to the Institute of Navigation* under the general heading of "Interplanetary Travel." The first of these was an introduction called *The Dynamics of Space Flight* and given by Mr. A. C. Clarke. As this paper is on the same lines as the one with the same title by Mr. Clarke in a previous *Journal* [**8**, 2, March, 1949], it will not be described in detail here.

The second paper entitled *Some Problems of Interplanetary Navigation* was given by Dr. R. d'E. Atkinson of the Royal Observatory, Greenwich. Dr. Atkinson began by limiting the scope of his paper to the problem of how a ship with Mars or Venus as its destination would prevent itself from getting lost when thrown entirely on its own resources. Furthermore he excluded the question of radio aids at the outset and considered essentially optical methods of position fixing. Thus this should be considered as a specialist paper rather than as a general treatment of the problem of navigation as a whole; indeed, Dr. Atkinson made no claim to generality.

Dr. Atkinson then pointed out one rather common misconception. It is generally considered that the most economical orbit for reaching another planet is the ellipse which touches the Earth's orbit at one apse and the orbit of the target planet at the other. But this is an over-simplification of the problem because the target planet will not in general lie in the plane of the Ecliptic, due to the inclination of the planet's orbit. Venus, whose orbit is inclined at 3°·4, may be as much as 4,000,000 miles from the Ecliptic; the maximum distance of Mars is nearer 5,000,000 miles with an orbital inclination of 1°·9. A spaceship taking off from the Earth at longitude G from one node of Mars' orbit and travelling in an orbit of small inclination whose plane passes through the Sun, cannot be nearer to Mars, 180° after take-off, than about $(1{\cdot}52 \times 1{\cdot}9 \times \sin G)/57{\cdot}3$ astronomical units. For this distance to be as small as half a million miles, sin G must not exceed about 0·11, so that the Earth at take-off time must not be more than about 7° from a node of Mars' orbit, and only about one superior conjunction in 15 would be suitable. Appreciable further rocketry would be necessary to get closer in to Mars or to land.

Dr. Atkinson pointed out that if the rendezvous with the target planet is 180° away in longitude from the Earth at the instant of take-off, a slight inclination of the ship's orbit will not take care of the trouble; if one apse of the transfer orbit is in the Ecliptic, the other is as well.†

* *Journal of the Institute of Navigation*, **3**, No. 4, October, 1950.

† It may be noted, however, that an inclination of the ship's orbit could contribute towards the necessary displacement from the Ecliptic, if the change of longitude from take-off to rendezvous is other than 180°. For example, a point on the Earth's equator has (in general) a velocity component perpendicular to the Ecliptic due to the Earth's rotation and the tilt of its axis. This component has a maximum value of 0·2 km./sec. which would tilt the ship's orbit by about ¼°. Naturally, if this tilting is to be favourable the time of take-off from Earth must be very carefully chosen and there are other factors to take into account, such as the effect of the other components of velocity due to the Earth's rotation. If the orbit of Mars lies North of the Ecliptic at the longitude of take-off from Earth, then the ship would have to incline to the South so as to meet Mars at something less than 180° from take-off, the rendezvous being South of the Ecliptic.—D.J.C.

The energy required to give the correct N-S displacement is very little in comparison with that required for the initial take-off or final landing, and if the spaceship is accelerated very slowly but continually over a large part of the trajectory, the necessary displacement should be easy to arrange. Nevertheless it will be necessary to know the ship's Ecliptic latitude as well as its longitude and distance from the Sun, and this must be borne in mind when considering possible navigational techniques.

Dr. Atkinson then further limited the scope of his paper by excluding any discussion of the problems raised if the spaceship wishes to go into a "satellite" orbit round, or land on, the target planet, and restricted his remarks to the problem of fixing the ship's position when in a free solar orbit. His first suggestion was that the ship could be located by taking three observations (reasonably well separated in time) of the apparent place of a planet; this method is similar to that used to determining a comet's orbit from Earth. But Dr. Atkinson dismissed this as impracticable due to the large amount of computation necessary. A much better method would be to locate the ship on two lines by simultaneous observations of two planets. By using photoelectric methods of determining a planet's apparent place, the accuracy of a position fix would be a thousand miles or so if planets with small apparent radii are used for the observations.

Later, in the discussion, Mr. D. H. Sadler (H.M. Nautical Almanac Office) suggested that observations on four or five planets would give quite an accurate position fix. Dr. Atkinson agreed, but thought that high accuracy is not necessary and that a simple method of fixing is preferable to one which would require an electronic computer for its execution.*

In his paper, Dr. Atkinson next mentioned the possibility of supplying the ship with an ephemeris of the apparent places of the planets in question for the voyage as planned. Observations would give the departures of the places from prediction and corrective action taken accordingly. But besides making it necessary to start the voyage promptly at the time planned, this would again mean considerable computation to deduce from the observations the required correction to the orbit.

As a simpler alternative, Dr. Atkinson suggested that the ship always be orientated so that some specified axis pointed towards the Sun. The direction of this fundamental axis could then be used exactly as the direction of gravity is used in surface navigation; the angles made with this direction by the lines to two or three stars would yield the ship's heliocentric latitude and longitude. The orientation of the ship could be achieved by photoelectric equipment placed outside the ship and it should not be difficult to maintain it accurately to one-tenth of a minute of arc by a gyro servomechanism. With this accuracy, the

* Here, Dr. Atkinson was referring to a computer carried on the ship. The scope of his paper did not include a discussion of possible telemetering techniques, using a computing engine of any required size on Earth to deal with positional data transmitted from the ship. The limiting factors here would be the power of the signals which could be sent from the ship (the stringent economy necessary in payload would mean that the weight of units would have to be kept as low as possible), and, as Mr. Clarke suggested, the limit to receiver sensitivity set by galactic noise. Telemetering techniques might be useful when the ship is within reasonable distance of Earth, but at great distances or behind the Moon or Sun the ship would again be thrown on its own resources.—D.J.C.

error of a fix would be about 5,000 miles in each of the two tangential coordinates at the distance of Mars.

The distance from the Sun could be obtained from one observation, in longitude only, on a small planet reasonably near quadrature and the error in the radial direction should be appreciably less than 5,000 miles near Mars' orbit. Alternatively, measurement of the Sun's apparent size would give its distance, although the radial accuracy at the distance of Mars would only be about 40,000 miles. This accuracy, Dr. Atkinson considered, would be good enough except perhaps for the last half million miles, when it would probably be desirable to make observations on Mars itself. Measurement of the apparent diameter would give the distance. Dr. Atkinson did not discuss the possibility of using radar techniques, which might give very accurate results. If a landing was to be made, radar ranging would give not only distance but also the rate of approach, as Mr. Clarke pointed out later in the discussion.

In general, the deduction of the ship's latitude and longitude from observations on the angular positions of stars would involve the solution of spherical triangles, as in ordinary navigation on the Earth. But if the ship's orbit is reasonably near the Ecliptic the triangles can be reduced to plane triangles with very little loss in accuracy and considerable gain in simplicity, by making longitude observations on stars within 5° of the Ecliptic and latitude observations on stars near the poles. The calculation for longitude would be further simplified if the star for measurement is near quadrature, since the answer is then almost independent of the latitude. Canopus, reasonably near the South Ecliptic pole, could be used for latitude observations; better still ζ Draconis, which is within a degree of the North pole, but this is only a third magnitude star. In practice, the ship could be supplied with three ephemerides, namely one for the Sun's distance, one for the elongation of a suitable longitude star and one for the elongation of the selected pole star, and would then keep these three bodies under continuous observation, ignoring all others.*

Dr. Atkinson continued by pointing out that the deviations of the observed from the predicted coordinates could be corrected by jets arranged parallel to the coordinate axes. Correction of either the longitude or the radius vector will have some influence on both because of the law of areas; for example, if the latitude and longitude are correct at some given time and were so in the past, but the radius vector has become too small, an increase in the radial velocity should be accompanied by a tangential impulse so that the angular velocity remains correct even though the radius vector has gone up. To avoid hunting it would probably be desirable to have an automatic "killer" for every navigational impulse applied to the ship.

To allow for the N-S displacement of the target planet when take-off and rendezvous on the ship orbit are 180° apart, it would probably be advantageous to apply deliberately a change of direction of a degree or so roughly half way between Earth and target. The transverse velocity necessary would be about

* At the beginning of his paper, Dr. Atkinson had said that the navigation problem seems to depend surprisingly little on whether the ship is manned or not. But perhaps here is a case where a human crew would have the advantage over automatic contrivances, for it might be very difficult to ensure that a photoelectric tracking device will "lock on" to a chosen star and not to some other.—D.J.C.

½ km./sec. and correct to about 1 per cent., but its exact direction would not be so critical. The impulses to correct deviations from predicted course would probably not be so large as this in general, the limit depending on the accuracy of observation and the length of time available to make good the deviation. For example, if it is desired to correct an error of 50,000 miles in the radius vector over a period of 5 days, the velocity component required is roughly 0·2 km./sec. plus the velocity error which caused the positional error to begin with.

Finally, Dr. Atkinson suggested two astronomical techniques which might be employed to find components of the ship's velocity, although he doubted their practical utility. The first method is to measure the Doppler shift of the Sun's spectrum so as to obtain an estimate of the radial velocity. Photographic techniques would have to be used, in conjunction with a large spectroscope, and the whole method is decidedly cumbrous for automatic operation. The other method is to measure the apparent displacement of stars towards the apex of the ship's motion due to aberration. The displacement towards the apex amounts to $(v \sin A)/c$, where A is the angular distance from the apex- v is the ship's velocity and c is the velocity of light. The maximum displace, ment is for stars 90° from the apex and is 20″·5 for the Earth's mean speed of 29·8 km./sec. The mean places of the fixed stars, free of aberration except for a small known term, are known with an accuracy of about one-tenth of a second of arc all over the celestial sphere, so that if the angular separation of the stars can be measured to an accuracy of a fifth of a second, the magnitude and direction of the ship's velocity could be derived to about 1 per cent. This would require a high degree of mechanical precision in the instruments and it might be hard to eliminate systematic errors in the apparatus due to stresses at take-off.

In reply to questions, Dr. Atkinson stated that it might be extremely difficult to make time checks of any accuracy, although he did not consider it essential to do so in view of the uncertainties in position. He did not think that a standard chronometer would vary in performance under two gravities instead of one or in a free fall, but he did not commit himself to this; there should be no difficulty with crystal clocks, however. It would not be easy to make time checks by observations on planets' satellites or the Earth's rotation.

Dr. Atkinson, also in reply to a question, thought that angular tracking of a ship from Earth would be very difficult. If a ship was to be fitted with a radar responder, the directional accuracy at the distance of the Moon would not be great, even if an extended aerial system were to be used.

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SURVEY OF DEVELOPMENT OF LIQUID ROCKETS IN GERMANY AND THEIR FUTURE PROSPECTS

By Prof. W. von Braun*

(Some five years ago, immediately following the end of the war, there was a period of great activity by Anglo-American teams of interrogators, engaged on the task of investigating and evaluating all the results of the German scientific war effort. These teams issued reports on their findings, and many of these reports dealt with the work of von Braun and his collaborators at Peenemünde.

One of these (C.I.O.S. Item 4 & 6, File No. XXVIII–56, "Rockets and Guided Missiles," by Mr. Gollin of the British Ministry of Supply) was notable for its inclusion of the following essay. We are reprinting it now (by kind permission of the Ministry of Supply) in the belief that both its authorship and its subject-matter render it of great historical interest.—Ed.)

We consider the A.4 stratospheric rocket developed by us (known to the public as V.2) as an intermediate solution conditioned by this war, a solution which still has certain inherent shortcomings, and which compares with the future possibilities of the art about in the same way as a bomber plane of the last war compares with a modern bomber or large passenger plane.

We are convinced that a complete mastery of the art of rockets will change conditions in the world in much the same way as did the mastery of aeronautics and that this change will apply both to the civilian and the military aspects of their use. We know, on the other hand, from our past experience, that a complete mastery of the art is only possible if large sums of money are expended on its development and that setbacks and sacrifices will occur, such as was the case in the development of aircraft.

A few private groups of inventors started serious work on liquid rocket development in Germany in the years 1929–30. One of these groups, called "Rocket Flying Field Berlin," located at Berlin-Reineckendorf, had Prof. Dr. von Braun as a student among its members. Simple fundamental tests with rocket combustion chambers were carried out there, and small uncontrolled liquid rockets were fired, which reached heights up to 1,000 metres, and landed by means of a parachute. At the end of 1932 the work of these groups was slowed down by lack of cash, but the Army Weapons Department was interested in carrying on the work, and took over the services first of Prof. von Braun, and later of most of the other engineers.

This special division of the Army Weapons Department was put under the direction of Dr. Ing. h.c. Dornberger, and the first rockets developed by them were designed solely for experimental purposes, and were of no military value. In 1934, liquid rockets of the A.2 type were successfully tried out. They had a thrust of 300 kg., were directly stabilised by means of a large gyro, and reached a height of approximately 2,000 metres. In 1938 the first trials were carried out with liquid rockets of the A.3 and A.5 types, which were fitted with an automatic control system and rudders in the gas stream. These rockets reached a height of 12 km. when fired vertically, and had a range of

* Written in Jun , 1945.

18 km. when fired at an angle. They could land in both cases by means of parachutes, and be used again.

In view of the successful results achieved with liquid rockets, it was decided in 1936 to begin with the construction of a large experimental establishment for rocket development at Peenemünde on the Baltic. It was already recognised at that time that the development of rockets showed great promise in the field of aeronautics as well as in that of artillery, and it was therefore decided to build two separate establishments at Peenemünde, one for the Army and one for the Air Force, which are two distinct branches of the *Wehrmacht* in Germany. At Peenemünde-Ost, comprehensive test beds and workshop facilities were set up for the construction and testing of rocket drives and controls, whilst at Peenemünde-West an airfield was built for testing rocket aircraft, and pilotless rocket propelled aircraft, as well as auxiliary drives for standard aircraft, such as rocket assisted take-off devices. The cost of construction of the complete installation at Peenemünde totalled approximately 300,000,000 Marks after completion. This close proximity of the rocket development work to the aeronautical development side is one of the principal reasons for the success of the work undertaken at Peenemünde.

The following considerations were decisive in the choice of Peenemünde, and these considerations will always be important when choosing a site for rocket development work:—

(*a*) Secluded position, far away from large towns. (Safety during launching, nuisance caused by noise of large test beds.)

(*b*) Favourable weather conditions (during firing and flight trials of rockets and rocket aircraft blue skies are always desirable).

(*c*) Reasonably satisfactory communications. The development work necessitates constant close contact between development engineers and certain branches of industry.

The successful experimental rocket A.5, previously mentioned, had a thrust of 1,500 kg. lasting 45 seconds. Basing on the results obtained with the rocket, the order was given to develop a long distance rocket with a range of 250 km., as high an accuracy as possible, and a war-head weighing 1,000 kg. This rocket, known as A.4, was first launched successfully in October, 1942. The A.4 has a thrust of 25 tons, for a combustion period of 68 seconds max. It is fired vertically from a firing table, without guides of any sort, as was the case with all the previous rockets. The steering of the rocket to an inclined position is effected by means of a "programme" apparatus. The lateral direction is determined by the exact setting of a turn-table on the firing table. The exact range is determined by shutting off the propulsion unit upon reaching a previously calculated speed.

The development of the A.4 required a great number of preliminary scientific investigations, the most important of which are briefly outlined below:—

(*a*) Wind tunnel tests at all ranges of air speeds between 0 and 1,500 metres per second. During these tests, such factors as the stability of the

rocket, the distribution of the air pressure, the working of the rudders, and several more, were investigated, apart from the drag measurements, both with and without exhaust gas stream. Both the supersonic wind tunnel and the measuring methods had to be developed over a period of years of hard work.

(*b*) Test bed investigations on the combustion chamber of the rocket, and on the complete propulsion unit. This, too, necessitated the development of appropriate test beds and measuring methods.

(*c*) Investigations connected with the steering of the rocket at all ranges of airspeeds covered by the rocket. For this purpose, a special technique of models, reproducing the attitude of the rocket in flight, was developed.

(*d*) Development of measuring methods for plotting the complete flight path of the rocket.

(*e*) Investigation connected with the influence of the exhaust gas stream on the wireless communication between rocket and ground, etc.

In view of the increasing strength of the numbers of fighter aircraft in England, and the resulting increased losses of bombers operating against England, orders were given at the end of 1942 to produce the A.4 rocket in quantities. The accuracy of aim was still unsatisfactory, and limited the use of the rocket to large area targets, foremost of which was London. Nevertheless, some 60,000 to 65,000 drawing modifications were required before the first experimental A.4 rocket became a real series production job. This indicates how many absolutely new problems arose during the trials of the A.4, which was subjected to hitherto unknown physical conditions.

Meanwhile the development side was attempting to improve the accuracy of aim of the rocket. To this end, radio guide beam devices were developed to improve the lateral direction; and improved propulsion unit cut-off devices to reduce the dispersion in range. These improvements, however, were incorporated operationally on a small scale only, and were in use chiefly in the attack on the harbour at Antwerp.

The original objective of further development was to produce long distance rockets of greater range. It should be noted here that the maximum ranges up to 480 km. were achieved thanks to certain improvements, which, however, never came into operational use.

Certain A.4 rockets were used to carry out vertical trajectory trials, and a maximum ceiling of 172 km. was reached during these trials.

It was planned in the spring of 1945 to fire vertically from an island situated near Peenemünde a few A.4 rockets equipped with special instruments for research into the top layer of the atmosphere. The measuring instruments were put in a water tight container capable of floating, which was to have descended by parachute. This project, all preparations for which were completed, could not be carried out on account of military events. It could be done in a short time, however, with some of the A.4 rockets still in hand.

The problem of increasing the range of the A.4 after completion of the A.4

development programme could only be carried on at a greatly reduced rate, as the development of guided anti-aircraft rockets was given first priority and absorbed much of the personnel, in consequence of the increasing air superiority of the Allies. A rocket for this purpose was developed at Peenemünde, bearing the code name "Wasserfall." This rocket was also propelled by liquid fuel, and could be guided by radio from the ground on to flying targets. Various successful tests were carried out, but series production of the weapon was not achieved.

A further development of the A.4 long-distance rocket is the A.9, on which work was done as far as the priority work on "Wasserfall" would allow. The propulsion unit was the same as for A.4. The A.9 rocket, however, had wings, which enabled it to glide through the stratosphere. This enables the flight path to be increased to such an extent that the range of the A.9 was nearly double that of the A.4, i.e. approximately 600 km., notwithstanding the fact that the fuel consumption of the A.9 was no greater than that of the A.4. However, development could not be completed on account of the end of the war. Special control devices would have given the A.9 at least the same accuracy as the A.4. It was proposed that the weapon should go into a vertical dive at the end of the glide, similar to that of the V.1.

As a further development, it was intended to design the A.9 winged rocket to carry a crew. For that purpose the rocket was to be equipped with a retracting undercarriage, a pressurised cabin for the pilot, manually operated steering gear for use when landing, and special aerodynamic aids to landing. The landing speed of this piloted A.9 rocket would have been as low as 160 km. per hour, as it would have contained very little fuel on landing, and would consequently have been light. This piloted A.9 rocket would cover a distance of 600 km. in approximately 17 minutes.

The range of the A.9, both in the piloted and pilotless versions, could be increased considerably if the propulsion unit were switched on only after the rocket had attained a certain initial velocity. There were two possible ways of achieving this end:—

(1) Use of a long catapult with only a slight gradient, which would have given the rocket an initial velocity of approximately 350 m./sec. There was experience of this type of catapult to hand at Peenemünde, as such a catapult developed by an industrial firm for launching the V.1, was tried out at Peenemünde. Experience showed that catapults could be built for launching at supersonic speed. These high speeds are essential for rockets such as A.9, because the rocket is completely filled with fuel at the start and would not fly if it left the catapult at lower speeds.

(2) Development of a large assisted take-off rocket of 200 tons thrust, on which the A.9 rocket would be mounted, and which would give the latter an initial velocity of 1,200 metres per second. After the assisted take-off rocket had exhausted its fuel, the A.9 would become separated from it, and its own propulsion unit would be switched on. The maximum speed of the A.9 at the end of its power drive under these

conditions would be approximately 2,800 metres per second, which would mean that this combination could give the A.9 a range of approximately 5,000 km., both in the piloted and the pilotless versions. The large assisted take-off rocket, called A.10, was to be equipped with air brakes and a special parachute, which would have enabled it to be used again after alighting on water.

It was proposed to launch the A.9/A.10 combination vertically, this obviating the necessity of erecting large ground launching devices.

In the more distant future, the development of liquid rockets offers in our opinion the following possibilities, some of which are of tremendous significance:

(1) Development of long range commercial planes and long range bombers for ultra high speeds. The flight duration of a fast rocket aircraft going from Europe to America would be approximately 40 minutes. It would even be possible to build very long range bombers, which would turn round at supersonic speeds in a very wide curve after having released their bombs, and return in a glide to land at their point of departure. The high speed of such aircraft would make defence against it ineffective with present-day means.

(2) Construction of multistage piloted rockets, which would reach a maximum speed of over 7,500 metres per second outside the Earth's atmosphere. At such speeds the rocket would not return to Earth, as gravity and centrifugal force would balance each other out. In such a case the rocket would fly along a gravitational trajectory, without any power, around the earth in the same way as the moon. According to the distance of the trajectory from the Earth, the rocket would complete one circuit around the Earth in any time between $1\frac{1}{2}$ hours and several days. The whole of the Earth's surface could be continuously observed from such a rocket. The crew could be equipped with very powerful telescopes, and be able to observe even small objects, such as ships, icebergs, troop movements, constructional work, etc. They could also carry out physical and astronomical research on problems which could only be tackled at that altitude, due to the absence of the atmosphere. The importance of such an "observation platform" in the scientific, economic and military spheres is obvious; when the crew of the rocket want to return to Earth, all they need to do is to reduce the speed of the rocket slightly, which can be done by rocket propulsion. The rocket then enters the upper layers of the atmosphere tangentially, and its speed is gradually reduced by friction. Finally, it can land like an ordinary aeroplane by means of wings and auxiliary gear. It would also be possible to relieve the crew and provision the "observation platform" by means of another rocket, which would climb up to the platform and pull up beside it.

(3) Instead of having a rocket set up an "observation platform" outside the Earth, it would be possible later on to build a station specially for the purpose, and send the components up into the interstellar spaces by means of rockets, to be erected there. The erection could be

easy, as the components would have no weight in the state of free gravitation. The work would be done by men who would float in space, wearing divers' suits, and who could move at will in space by means of small rocket propulsion units, the nozzles of which they would point in the required direction.

(4) According to a proposal by the German scientist Prof. Oberth, an observation station of this type could be equipped with an enormous mirror, consisting of a huge net of steel wire on to which thin metal foils could be suspended. A mirror of this nature would have a diameter of many kilometres, and its component facets could be controlled by the station which would enable the heat and light of the sun to be concentrated on selected points of the Earth's surface. This would enable large towns, for instance, to get sunlight during the evening hours. The weather, too, can be influenced by systematic concentration of the sun's rays on to certain regions. Rain could be induced to fall on regions hit by drought, by concentrating the sun's rays on to distant lakes and seas, and increasing their evaporation. The clouds thus formed could be driven to the required spot by influencing the centres of low and high pressure through radiation from other facets of the mirror. If the mirror is made large enough, and it could be of extremely light construction, it would even appear possible to generate deadly degrees of heat at certain spots of the Earth's surface.

(5) When the art of rockets is developed further, it will be possible to go to other planets, first of all the moon. The scientific importance of such trips is obvious. In this connection, we see possibilities in the combination of the work done all over the world in connection with the harnessing of atomic energy together with the development of rockets, the consequence of which cannot yet be fully predicted.

To conclude, we think after what has been said above, that a well-planned development of the art of rockets will have revolutionary consequences in the scientific and military spheres, as in that of civilisation generally, much in the same way as the development of aviation has brought revolutionary changes in the last 50 years.

A prophecy regarding the development of aviation made in 1895 and covering the next 50 years, and corresponding to the actual facts, would have appeared at least as fantastic then as does the present forecast of the possibilities of rocket development.

In the same way as the development of aviation was not the work of a single man, but became possible thanks to the combined experience of many thousands of specialists, who concentrated exclusively on this one branch of science for years, so the development of the art of rockets will require a systematic effort by all specialists who have gained experience on this subject.

The programme of work carried out at Peenemunde and briefly described by von Braun in the above discussion of the overall potentialities of rocketry, still remains the most ambitious and productive one in the history of the subject to date. Further details of the achievements of this wartime German establishment are given in the paper "A Review of German Long-Range Rocket Development", by W. G. A. Perring, J.R.Ae.S., July 1946. See also J.B.I.S., 1948, **7**, *92 ("Table of German 'A' Projects"), and 1950,* **9**, *155–157 (data on A.9/A.10 project).*

NOTES AND NEWS

Increased Subscription Rates

As members will see from a circular letter enclosed with this *Journal*, the Council is proposing to increase the annual subscription rates and entrance fee to the following new scale:—

	£	s.	d.	
Fellows ..	2	12	6	
Members ..	1	11	6	(Under the age of 21, £1 1s. 0d.)
Entrance fee ..		10	6	

This resolution will be the subject of a postal ballot (a voting form for which is enclosed herewith), and will be the subject of an Extraordinary General Meeting on May 26, 1951, to be held at the Kent Room of Caxton Hall, commencing at 6 p.m.

If approved by the membership, the new scales will apply to all new members joining after June 30, 1951, and for annual subscriptions falling due from existing members on January 1, 1952.

Distribution of Membership

An analysis of the geographical distribution of the membership at September 30, 1950, was recently undertaken by Mr. P. R. Freshwater, with results as follows:—

(*a*) *Members resident in the British Isles*—			
London area	178		
Southern counties	308		
Midlands	101		
Northern Counties	124		
Scotland, Wales and Ireland ..	53		
	—	764	(83 per cent.)
(*b*) *Members Abroad*—			
Europe	37		
The Americas	87		
Australia and New Zealand ..	19		
Rest of the World	18		
	—	161	(17 per cent.)
Total		925	

North Western Branch—Change of Meeting

The "Short Paper and Discussion Evening" originally scheduled for 19th May has been changed to 26TH MAY, 1951, the venue and time remaining unaltered. There will be no meeting on 19th May.

Obituary

We regret to announce the death of a distinguished Swiss member, Dr. Robert Paganini, at the age of 85. Dr. Paganini had been a member of the B.I.S. since 1946 and was an expert on air-mail history.

From the World's Press

The "Business and Finance" section of *Time* for January 1 had something to say about the present status of the Aerojet Engineering Corporation. With over 1,600 employees and 25 million dollars' worth of orders to fulfil, the company is still rapidly expanding; it finds its present 10 million dollar plant at Azusa, California, inadequate, and is building a second, at a cost of 6 million dollars, on a 7,200 acre site near Sacramento. Apart from rocket power plants for aircraft and missiles, Aerojet are stated to be working on rocket units for underwater propulsion and a rocket-powered drill for oil wells.

* * * *

Borrowing an idea already used to good effect by André Maurois, Bernard Newman, and others, the *Saturday Evening Post* last September carried a very entertaining story by Rear-Admiral Gallery (U.S.N.) about a group of men who frighten the world into peace and co-operation by staging an elaborate, though wholly fictitious, threat of invasion from another planet. (One of the picture captions was: "For once, even Vishinsky was agreeing with the American delegation . . .," which reminds us of a winning entry in a recent *News-Chronicle* competition for the 1951 headline readers would most like to see: "Martian invasion threat—MacArthur and Stalin confer.") In the Satevepost story, much is said about a "British Interplanetary Space Society," which unwittingly co-operates with the hoaxers by receiving a "reply" in ancient Hebrew to one of its regular monthly broadcasts to Mars!

We should be delighted to participate in any such project having reasonable prospects of success, without the need to be hoodwinked ourselves. . . . On further reflection, we believe we have at least one member, in a University post in Palestine, who might even manage the ancient Hebrew.

Further proof that you can't keep a good idea down was afforded by another recent item in *The Saturday Evening Post*: "In this new age of rockets, a trip to the Moon is fast becoming not only possible, but desirable." The same observation, variously paraphrased, was made to us by several recipients of our B.I.S. Christmas cards this year, but on the whole, we think the best epigrammatic value was given by the wording chosen by our new Chairman long before Hiroshima: "The advent of atomic energy makes interplanetary travel not only possible, but *imperative*." But we wonder—who told it to *him*?!

* * * *

In an amusing little essay published in the *News-Chronicle* during December (and subsequently quoted in *Time*), J. B. Priestley expressed irritation at all the current talk of interplanetary travel, and pleaded for "One world at a time, please." Challenged by Val Cleaver, he admitted that his observations were not meant to be taken too seriously, but would not agree with our more optimistic ex-Chairman that he had been too harsh on the twentieth century in saying, in the same essay, that Man was almost beginning to lose sight of civilization. Surely the Yorkshire Sage would concede that, as against the nineteenth century, the twentieth can show a host of social, industrial, medical, and educational reforms, to say nothing of the colonial ones, as some compensation for Belsen and atomic warfare? And what about the sheer *idea* of UNO

and the League, which was formulated in our time? Perhaps the Martians may consider us fit to associate with, after all; dreadful thought—supposing they turn out to be even worse stinkers than we are?

* * * *

The biggest meteorite crater in the world has recently been discovered at Ungava, in the barren wastes of Canada's Northern Quebec; it is thought that the meteor probably fell between 3,000 and 5,000 years ago. This adds point to a picturesque new theory accounting for the famous Siberian "meteor" of 1908. Writing in the Soviet magazine *Knowledge-Power*, S. Lyagunov says that no trace of materials of conclusively meteoric origin has ever been found in the craters near the Tunguska River at Taiga, and suggests that they may really be the result of an unsuccessful crash-landing by a spaceship from another planet!

Reported at greater length in *The Montreal Gazette* than in the many other accounts we have seen of his article, Lyagunov is stated to picture "the great spaceship as being crippled by a collision with a meteor. . . . it tried to alight in the Mongolian Desert, but overshot its mark by some hundreds of miles, (and) finding itself over the rugged terrain of Central Siberia, tried to gain altitude by using its rocket motors, which were probably atomic-powered. At this point, the ship exploded and disintegrated, leaving no trace except the dust that filled the Earth's atmosphere."

When we first saw the headlines of the above story, we thought we were about to be regaled by evidence that Russia had invented, not only radio and the aeroplane, but also the spaceship. However, it turned out, more or less, that she had merely seen the first flying saucer (American papers, please note). On second thoughts, perhaps we had better not try to be funny on this subject of astronautical priority; after all, Ziolkovsky's first paper on the subject *was* printed in 1903.

* * * *

We were gratified by the many extremely favourable reviews of the Ley-Bonestell book, *Conquest of Space*, which appeared in the British Press on the publication of the Sidgwick and Jackson edition over here. The *Times*, always authoritative, commissioned none other than Fred Hoyle to write theirs, and so the readers of the famous "Thunderer" were informed: "One has to be an optimist to believe that a trip to the Moon and back will be safely accomplished within the next hundred years. But the odds are that it will be accomplished one day." Fred Hoyle, we imagine, is not often accused of scientific conservatism or a reluctance to make forthright statements, but we think he might fairly be so charged on this occasion. In other words, we *are* optimists. . . .

According to *The Daily Mail* for January 6, so is Sir Harry Mason Garner, Chief Scientist of the Ministry of Supply. He told youngsters visiting the Schoolboys' Exhibition in London that he was convinced that many of them would see the first successful flights to the Moon, Mars, and Venus—with only the reservation that "Venus is a very hot planet." This latter qualification must have worried many of his audience, who might have pointed out that their

current hero, Dan Dare, together with his faithful henchman Digby, seemed to be thriving in the Venusian atmosphere, in the pages of the ever-popular *Eagle*.

Reverting to the "Conquest" reviews, we were interested to find a long one in *The Daily Worker*, and scanned it eagerly to learn how this particular topic could be turned to serve the party line. Sure enough, we duly read: "But (the extension of our knowledge and control over nature) is not the main aim of the rocket development work. The fact that it is carried out under the military organization of the U.S. is clear enough indication of the real purposes behind it—the preparation for a new war. . . . Under the sham of 'defensive' war preparations, a considerable amount of work is being done on the development of long-range guided weapons, the idea being, of course, to produce rockets which can be used to carry atom bombs to burn and devastate the peaceful cities of the Soviet Union, Eastern Europe or Asia."

It is, "of course," well-known that Russian guided missiles, on reaching their targets, will merely release a cloud of sweet Marxian scent, together with a flock of doves to coo gently at the Anglo-American workers.

* * * *

Something of a minor fanfare of trumpets in the British Press greeted the release of photographs (but no detailed information) on the "B.E.R.," which was also shown at the Schoolboys' Exhibition. We hastened to inspect this, in the hope that it might represent a first indication of practical large-scale British achievements in the field of rocketry. Our hopes were dashed, however, when we saw that the 20 ft.-long missile appeared to rely for its propulsion on a few not-very-large solid-propellant rocket motors; clearly this is no V2, Viking, or even Aerobee, and is incapable of attaining any extreme speeds or altitudes, however useful it may be for whatever purpose it is intended. In fact, the whole affair seems rather reminiscent of the small liquid-propellant motor "for a research aircraft" exhibited on the Ministry of Supply stand at the Farnborough S.B.A.C. Show last year (see this *Journal* for November, 1950).

* * * *

A somewhat tortuous editorial in *The Aeroplane* for December 15, after discussing electronic computers, the vacancy for a Secretary of the R.Ae.S., the history of aeronautics, and a few other subjects, appears to suggest that the Royal Aeronautical Society should "extend its aims to provide for . . . transport throughout our atmosphere *and beyond it.*" (The italics are ours.)

Now, we admit that one thing leads to another (as in the editorial in question), and we are grateful for the friendly references to astronautics made by the writer during the development of his literary game of Consequences, also for any similar interest in the subject now shown by the wholly admirable R.Ae.S. However, at this early stage, we wish to stake our claim to the extreme upper regions of the atmosphere, into which no aeroplane Within the Meaning of the Act can venture, and especially to those "beyond it." How would the R.Ae.S., now a venerable 84 years of age, have felt if (say) the Institute of Naval Architects had decided to take over aviation interests as soon as they became moderately respectable in the early years of the present century?

The Goddard Memorial Exhibit

The formal opening of the Goddard Memorial Exhibit took place on December 1, 1950, at the Aeronautical Museum of the Institute of the Aeronautical Sciences, New York, in the presence of Mrs. Goddard and American rocket and aviation experts. Dr. Goddard's entire library on rocket propulsion (including his own records of his experiments) and hundreds of the actual rocket parts and mechanisms tested in the course of his work have been presented to the Institute by Mrs. Goddard and will be part of the permanent exhibit of the museum. The collection includes a prototype of a "bazooka" developed and ready for production at the end of World War I, as well as many examples of liquid-fuel rocket motors, controls, tanks, instrumentation, firing mechanisms, fuel pumps, turbines, etc., from Dr. Goddard's experiments at Auburn, Roswell and Annapolis. Completing the exhibit are some of the latest JATO and rocket engines, loaned by the United States Navy and Reaction Motors, as examples of further developments in rocket engineering since Dr. Goddard's death.

General view of approximately one half of the Exhibit.

Suspension of *Pacific Rockets*

The Pacific Rocket Society has recently announced the suspension of its Journal, hitherto received by Fellows of the B.I.S. under an exchange agreement.

The suspension is due to the fact that the P.R.S. has always placed greater emphasis upon experiments conducted by that Society in the Mojave Desert, and wishes at the present time to enlarge its activities in this direction still further.

Acknowledgments

The Council wish to acknowledge with grateful thanks the generous donation of the following books by M. Ananoff:—

Le Problème des Voyages interplanétaires, by M. Ananoff (1934).
La Navigation Interplanétaire, by M. Ananoff (1935).
La fusée de guerre, by M. Ananoff (1938).
La Vie Serait-elle Possible a bord de Satellites Artificiels de la Terre ou de Projectiles Astronautiques, by M. Esclangon (1950).
The Eminent Scientist K. E. Tsiolkovskii, by Professor A. A. Kosmodem'yanskii (1949) (in Russian).
Sur Les Autres Mondes, by Lucien Rudaux (1937).

They extend their further thanks also to Ing. Friedrich Schmiedl, who has very kindly presented to the Society's archives five rocket mail souvenir postcards.

ABSTRACTS

Edited by J. HUMPHRIES

Abbreviations of titles of journals were given in the May, 1950 issue of the *Journal* and addenda have appeared in all subsequent issues. The following is a further addendum to the list.

Astr. J.	Astronomical Journal.
Canad. J. Res.	Canadian Journal of Research.
J. Roy. Astr. Soc. Can.	Journal of the Royal Astronomical Society of Canada.
Mem. B.A.A.	Memoirs of the British Astronomical Association.
Sci. Mon.	Scientific Monthly.

Many of the Abstracts noted are available on loan to members resident in the British Isles. Requests should be addressed to J. Humphries, 97, Churchill Avenue, Southcourt, Aylesbury, Bucks.

AIRCRAFT

(46) **Problems faced in designing famed X-1.** J. VAN LONKHUYZEN. *Aviation Wk.*, **54**, 22-4 (*1st Jan.*, 1951). History of the development of the aircraft including rocket motor, structural and aerodynamic problems.

ASTRONAUTICS

(47) **The space-station—a project for the future?** R. ENGEL, U. T. EÖDEWADT, K. HANISCH. *O.N.E.R.A.*, Paris, 76 pp. (*1st Sept.*, 1949). (*In German.*) [Excerpt published as "Earth satellite vehicles." R. ENGEL, *Interavia*, **5** (10), 500-2 (1950).] Outlines first of all the arguments in favour of various orbits and decides that for practical purposes a circular orbit at 557 km. altitude would be the most useful. A study is made of a station with a crew of 20 having a total weight of 510 tonnes. To build this would take about 3 years, cost 500 million dollars and require 375 flights by feeder rockets; only one in five of these feeders would be designed to return. Using propellants with an exhaust velocity of 2,180 m./sec. (at ground level) a 6-step rocket with an all-up weight of 220 tonnes would be needed to transport a 2 tonne payload into the orbit. It is suggested that only the bottom step of each feeder should be made recoverable and that the returnable feeders could be brought back with a minimum propellant expenditure by fitting wings and gliding down.

(48) **Astronautics enthusiasts.** A. ANANOFF. *Interavia*, **5** (10), 508-9 (1950). A history of the astronautical societies in Russia, Germany, Austria, United States, England, France, Spain, Netherlands, Canada, Argentina and Australia.

(49) **This Moon madness.** S. BANGS. *Interavia*, **5** (10), 503-7 (1950). The production of "Destination Moon."

(50) **The shape of ships to come.** W. LEY. *Interavia*, **5** (10), 496-9 (1950). Suggestions for the methods of operation of atomic-powered spaceships are made. Human problems in space such as effects of ultra-violet and cosmic rays are next discussed. Information on meteorite distribution is given and suggestions for protective measures made. The final section deals with true interplanetary voyages and the difficulties of position finding.

(51) **The interplanetary ocean.** W. SCHAUB. *Interavia*, **5** (10), 533-6 (1950). A discussion of the "gravity terrain" and singular points in the Sun-Earth system.

(52) **Electric spaceships, Pt. I.** H. OBERTH. *Radio-Electronics*, **22**, 32-4 (*Dec.*, 1950). Elementary considerations of the ion rocket.

See also abstract No. 80.

ASTRONOMY

(53) **Eleventh report of the lunar section of the B.A.A.** H. P. WILKINS. *Mem. B.A.A.*, **36**, Pt. 3, 43 pp. (*June*, 1950). Report of recent visual observations, primarily of fine detail, some attention being paid to little-known limb features.

(54) **Families of minor planets and related distributional problems.** D. BROUWER. *Astr. J.*, **55**, 162 (*Oct.*, 1950). A qualitative discussion of the age of the families and their orbital dispersion.

(55) **Current minor planet problems.** P. HERGET. *Astr. J.*, **55**, 165 (*Oct.*, 1950).

(56) **On the origin of asteroids.** G. P. KUIPER. *Astr. J.*, **55**, 164 (*Oct.*, 1950). General discussion of possible process of break-up of an original single planet.

(57) **Meteoric ionization.** P. M. MILLMAN. *J. Roy. Astr. Soc. Can.*, **44**, 209-20 (*Nov.-Dec.*, 1950). A general discussion of the information obtained from radar observations on the mechanism of interaction of meteors and the terrestrial atmosphere. (36 refs.)

(58) **Is there vegetation on Mars?** C. VON REGEL. *Weltraumfahrt*, (6), 139-40 (*Dec.*, 1950). (*In German.*) Review of the attempts to identify chlorophyll spectrographically.

(59) **Nature of the surface of the Moon.** J. C. JAEGER and A. F. A. HARPER. *Nature*, **166**, 1026 (16*th Dec.*, 1950). Shows that microwave measurements are consistent with the existence of a 2 mm. layer of dust on the surface.

(60) **The observation of an atmosphere around the planet Mercury.** A. DOLLFUS. *C.R. Acad. Sci., Paris*, **231**, 1430-2 (18*th Dec.*, 1950). (*In French.*) Measurements of the polarization of reflected light indicate an atmosphere with a surface pressure of about 1 mm. Hg.

BIOLOGY AND MEDICINE

(61) **Evaluation of present-day knowledge of cosmic radiation at extreme altitude in terms of the hazard to health.** H. J. SCHAEFER. *CADO Techn. Dig.*, **15**, 21-6 (*Oct.*, 1950). [Extensive abstract in *Engrs. Dig.*, **12**, 27-8 (*Jan.*, 1951).] The intensity of cosmic radiation increases with altitude. Since future aircraft may travel at very high altitudes (50,000-100,000 ft.) the author attempts to evaluate the effect of increased radiation on human beings in terms of numerical data now available. Danger of heavy nuclei rays is strictly limited to altitudes above 70,000 ft. Harmful effects are cumulative and it might take 20-100 hours to produce initial symptoms. At 90,000 ft. about 5,000 cells would be hit by one heavy nucleus which corresponds to 1.5 milliroentgens equivalent physical per 24 hours.

(62) **Silicon and extraterrestrial life forms.** F. R. FEARS. *J. Space Flight*, **2** (9), 5-6 (*Nov.*, 1950). Concludes that a life form based on silicon is highly improbable.

(63) **Effects of acceleration on the human body as shown by X-ray photographs.** H. VON DIRINGSHOFEN. *Weltraumfahrt*, (6), 135-7 (*Dec.*, 1950). (*In German.*) Showing the draining of blood from the heart.

(64) **The human body in space.** H. HABER. *Sci. Amer.*, **184**, 16-19 (*Jan.*, 1951). Discusses mainly the effects of acceleration and weightlessness. In free fall the chief troubles would be with the nervous system, sense organs and mind. The harmony of the sense mechanisms might be so disturbed that control of bodily movements would be difficult.

CHEMISTRY

(65) **Thermodynamic functions of hydrogen peroxide.** P. A. GIGUÈRE. *Canad. J. Res. B.*, **28**, 485-91 (*Aug.*, 1950). Calculated thermodynamic data for gaseous hydrogen peroxide over the temperature range 298-1500° K.

(66) **Heat capacities of several organic liquids.** E. W. HOUGH, D. M. MASON and B. H. SAGE. *J. Amer. Chem. Soc.*, **72**, 5775-7 (*Dec.*, 1950). Isobaric heat capacities of aniline, ethylene-diamine, furfuryl alcohol, isopropylamine, methyl alcohol and nitromethane.

(67) **Heat capacity of the hydrazine-water system.** E. W. HOUGH, D. M. MASON and B. H. SAGE. *J. Amer. Chem. Soc.*, **72**, 5774-5 (*Dec.*, 1950).

(68) **First and second pressure limits of explosion of diborane-oxygen mixtures.** F. P. PRICE. *J. Amer. Chem. Soc.*, **72**, 5361-5 (*Dec.*, 1950).

PROJECTILES

(69) **U.S. Navy fires into the ionosphere.** *Interavia*, **5** (10), 510 (1950). Description of the U.S.S. "Norton Sound" and its facilities for rocket firing.

(70) **Celestial mechanics and rockets.** H. BARTENBACH. *J. Space Flight*, **2** (9), 1-4 (*Nov.*, 1950). Method for calculating trajectories of long-range rockets.

(71) **The early history of rocket research.** J. W. SIRY. *Sci. Mon.*, **71**, 326-32 (*Nov.*, 1950).

(72) **Tactical use of guided missiles.** N. M. BENGTSON. *Ordnance*, **35**, 184-6 (*Nov.-Dec.*, 1950). Their potentialities in support of ground combat.

(73) **The Peenemuende rocket centre, Pt. 4.** K. A. EHRICKE. *Rocketscience*, **4**, 81-8 (*Dec.*, 1950). Deals with the period 1940-5. Much of this time was devoted to improving A-4 and developing anti-aircraft missiles C-2 and Taifun—both using nitric acid motors. The long-range A-9 and A-10 were on paper only although a winged A-4*b* was flown. Also mentioned are a three-step missile A-11 and a satellite missile A-12.

(74) **The optimum velocity, Pt. II.** H. OBERTH. *Rocketscience*, **4**, 75-80 (*Dec.*, 1950). Translation from "Wege zur Raumschiffahrt."

See also abstract No. 75.

RADIO AND ELECTRONICS

(75) **Project Typhoon aids missile designers.** D. A. ANDERTON. *Aviation Wk.*, **53**, 40-2 (18*th Dec.*, 1950). Electronic computer for plotting motion of missiles.

ROCKET MOTORS

(76) **Investigation of some rocket problems.** P. DROSSBACH. *Research Series of the G.F.W., Report No.* 3, 7 pp. (*In German.*) The first part deals with the adiabatic expansion of a mixture of atomic and molecular hydrogen. A method is developed taking reassociation into account and is applied to an example. It is then shown that a simple method deduced from kinetic gas theory gives approximately the same results. The second part deals with heat transfer in high temperature combustion chambers and suggests using mixtures of chemicals as wall materials which would combine in an endothermic reaction, for example calcium oxide and carbon.

(77) **R.C.A.F. gets Jato rockets for boosted take-offs.** *Canadian Aviation*, **23** (2), 21, 48 (1950).

(78) **Rocket engine by D.H. boosts power of jets.** *Canadian Aviation*, **23** (4), 42 (1950).

(79) **Rocket motor hydraulics.** G. P. SUTTON. *Machine Design*, **22**, 86-91 (*May*, 1950). Hydraulic problems encountered in flow control and chamber design. Accurate metering of propellants at high flows governs system design. Close tolerances are essential on injectors. Acceleration effects of up to 30 "g" in special anti-aircraft rockets produce extra hydraulic heads and introduce difficulties. Typical control valves are described.

(80) **Recent rocket research.** G. P. S. FINIGAN. *Rhodomagnetic Digest*, **2**, 7-11, 32 (*Aug.*, 1950). A general introductory review of rockets and space travel.

(81) **The influence of reassociation on the performance of rocket motors.** R. ENGEL and T. BOEDEWADT. *Rech. Aeronaut.*, (18), 23-33 (*Nov.-Dec.*, 1950). (*In French.*) In high temperature rockets where much energy is bound up in the combustion chamber it is possible, in principle, to regain some of this energy during expansion through the nozzle. Calculations have been made for 76 per cent. ethyl alcohol and liquid oxygen at a mixture ratio (fuel/oxidant) of 0.8 and chamber pressure 20 atmos. with the following assumptions, (*a*) complete reassociation up to exit, (*b*) complete reassociation up to throat only, and (*c*) no reassociation. The exhaust velocities in these cases are 2472, 2434 and 2405 m./sec. and exhaust temperatures 1958, 1801 and 1720° K. respectively.

(82) **Rocket-engine flight testing.** R. F. GOMPERTZ. *J. Amer. Rocket Soc.*, (83), 169-76 (*Dec.*, 1950). [Extensive abstract as "Rocket air tests," *Aviation Wk.*, **53**, 34-6 (18*th Dec.*, 1950).] A rocket-engine flight-test project is described. The necessity of obtaining better engine instrumentation during flight is stressed. Rocket-engine preflight check, propellant servicing, the rocket-powered phase of a flight-test project, and post-flight procedures are outlined, as presently conducted at an Air Force experimental flight-test base.

(83) **Introduction to rocket technique, Pt. 6.** H. OBERTH. *Ad. Astra.*, (10), 117-24 (*Dec.*, 1950). (*In German.*) Continuation from Pt. 5 of a discussion of the gas laws.

(84) **Energy loading of combustion chambers.** R. H. REICHEL. *Weltraumfahrt*, (6), 141-5 (*Dec.*, 1950). (*In German.*) Discusses energy requirements in relation to specific impulse. Shows that an atomic rocket working on the reflected ion principle would not be possible due to the very high energy losses.

(85) **Some statistical considerations of the jet alignment of rocket-powered vehicles.** A. L. STANLY. *J. Amer. Rocket Soc.*, (83), 155-68 (*Dec.*, 1950). Jet misalignment arises from mechanical and gaseous misalignments which in turn arise from manufacture. The relative effect of individual sources can be estimated statistically. Overall misalignment can be reduced by controlling the assembly alignments for groups of parts rather than for individual parts. Best results are obtained if direct control of overall misalignment is incorporated in the manufacturing assembly procedure.

(86) **Rockets and assisted take-off units for aircraft.** A. V. CLEAVER. *Engng.*, **170**, 575-7 (29*th Dec.*, 1950). Digest of lecture to R.Ae.S.

(87) **Rockets and R.A.T.O.** A. V. CLEAVER. *Flight*, **58**, 482-4 (30*th Nov.*, 1950). Digest of lecture to R.Ae.S.

ROCKET PROPELLANTS

(88) **Rocket propellants.** H. GARTMANN. *Interavia*, **5** (10), 527-9 (1950). The classification of propellants together with the properties and performances of specific fuels and oxidants.

(89) **Evaluating rocket propellant performance.** J. HIMPAN. *Interavia*, **5** (10), 530-2 (1950). Stresses the importance of propellant density and compares the performances of two rockets with propellants of widely varying densities. Proposes a new specific performance index which introduces both the effect of specific impulse and density on rocket performance.

(90) **Influence of the ambient pressure on the effects of shaped charges and the combustion of powders.** J. BASSET and J. BASSET. *C.R. Acad. Sci., Paris*, **231**, 1440-2 (18*th Dec.*, 1950). (*In French.*)

REVIEWS

Cosmic Rays

(By L. Jánossy, 2nd edition, 454 pp., 10 plates. International Series of Monographs on Physics, Oxford University Press, London. 1950.)

Many interesting new discoveries have emerged from the laboratories since the first edition of this book appeared in 1948, and the author has already found it necessary to modify and add to the original text. The second edition is substantially the same as the first and no attempt has been made to rewrite the work, this being deemed unwise with so many new developments proceeding in cosmic ray research. Indeed, the present state of affairs, happy though it may be for the experimenter, can hardly be considered propitious for the writer who faces the danger of seeing many of his statements outdated almost as soon as they have appeared in print. As an example of this we may quote from the present work, Chapter III, p. 118: "It must be pointed out, however, that there is no experimental evidence available to indicate the occurrence of neutral mesons." Within a few months of the appearance of this statement the existence of the neutral π-meson has been established almost conclusively, as a result of work at Berkeley and elsewhere, while the existence of an even heavier neutral meson of mass 800 electron-masses first suggested by Rochester and Butler in 1947, has been substantiated by further experiments of Anderson and Butler during the present year.

So much for the trials and tribulations of the writer in this rapidly expanding field. The author has faced up to the difficulties and has produced an extremley useful and comprehensive survey of the subject. It remains to be seen whether

he will be equal to the task of keeping the work up to date in the eventful years which lie ahead.

Dr. Jánossy, who is himself a very active worker in this field, has set out to present as complete a picture as possible. Theory, experiment and deduction have been blended together in a laudable manner and though the data is sometimes meagre and the interpretations somewhat insubstantial, the whole work presents a systematic and business-like appearance.

An historical introduction, which summarises briefly the main features in the development of our knowledge of cosmic rays, also serves as a synopsis of the text. Basic material, such as a brief account of experimental techniques and an outline of the theory of fast collisions, which underlies a great deal of the later calculations, is confined to two early chapters, with a few additions, in the form of appendices. The treatment of these matters is not very comprehensive and is probably aimed at the less specialised readers. The reviewer chooses to assume that Chapter II on experimental technique has been written for the benefit of the theoretician and Chapter III on collision theory for the benefit of the experimentalist.

A general outline of the phenomena observed at sea level and underground, in particular the types of particle which are observed, with some remarks on their absorption in matter and momentum distribution, follows in Chapter IV. The remaining chapters are devoted to detailed examination of the various processes which occur. The purpose of the examination is always clear, viz.: to deduce as much as possible about the nature of the primary particles which are incident upon the atmosphere and to learn as much as possible about the secondary processes which follow. Many of the inferences which the author draws are of a tentative nature, the experimental data is far from complete, though the gaps are rapidly being filled. That protons form one of the main constituents of the primary flux is now well established. The author describes a number of the experiments which have shown that fast nucleons give rise in collison processes to the mesons which form the penetrating component observed at sea level. It is one of the shortcomings of this book, that it has been written too soon to give an adequate account of the present-day studies of the formation of π-mesons in nucleon–nuclei collisions, and the subsequent proces of π–μ decay. The author's attention has been confined almost exclusively to the μ-meson, whose properties had been already fairly well established when the first edition was written. The μ-meson, whose decay into one or two electrons and a neutrino takes place with a half life of about 2μ secs., is of course much more readily observed in cosmic radiation than the charged π-mesons whose lifetime is smaller by a factor of a hundred. One of the interesting by-products in the observation of the decay of cosmic ray μ-mesons has been the verification of the time dilatation effect for extreme relativistic velocities. The author devotes many pages to an account of μ-meson decay and its effect on absorption measurements.

About 30 per cent. of the cosmic ray flux observed at sea level can be absorbed in a 10 cm. thick slab of lead, while the remainder is far more penetrating and can traverse a metre or more of lead with only slight attenutation. It is now well established that the hard component consists mainly of mesons

and primary protons, while the soft component consists of photons and electrons. A considerable amount of space is occupied in this book by a description of the properties of the soft component and the cascade process which arises as the result of the passage of high energy electrons or photons through the atmosphere. A photon of very high energy can give rise to a positron–electron pair in a close approach to an atomic nucleus, while a reverse process of photon emission may occur as the result of a radiative collision between an electron and nucleus. The cascade process which may take place through the mechanism of these two complimentary phenomena, can give rise to a shower of electrons, positrons and photons which may cover an area of hundreds of square metres and include tens of thousands of particles at sea level. Such showers require the existence of electrons or photons of energies up to 10^{10} Mev at the top of the atmosphere. The author subscribes to the view that these initial particles are primaries, since the alternative hypothesis that they arise as a result of meson-electron collisions or in the decay of μ-mesons appear to be untenable. The case against the meson-decay origin has taken a very interesting turn, however, since the publication of this book. Jánossy points out that for this to satisfy the observational data would require the existence of a neutral meson with half-life $\lesssim\sim 3 \times 10^{-14}$ secs. Work at Berkeley and Bristol has indicated that the neutral π-meson does, in fact, exist and that it decays into two gamma rays of equal energy. Furthermore, the Bristol workers estimate that the half-life $\sim 3 \times 10^{-14}$ secs. The high energy electrons or photons necessary for the initiation of extensive air showers could therefore arise from the decay of the neutral π-meson.

A fairly comprehensive account of the effect of the Earth's magnetic field on the primary cosmic ray particles is included in the text. One of the main consequences of this is a decrease in cosmic ray intensity between geomagnetic latitudes of $\pm$ 50° and the magnetic Equator. The fact that the intensity is constant above 50° implies that the primary energy spectrum is cut off below about 2,500 Mev, a fact which can be interpreted by assuming that the Sun has a magnetic moment of $1{\cdot}7 \times 10^{34}$ e.s.u.

An interesting collection of cloud chamber pictures and reproductions of photographic plates showing meson tracks, etc., is included in this excellent book.

L. R. S.

Introducing Astronomy

(By J. B. Sidgwick. Pp. 259. Illus. Faber & Faber, Ltd., 24, Russell Square, W.C.1. 15s. net.)

The author of this work follows closely in the footsteps of Denning's *Telescopic Work for Starlight Evenings*, and it is very likely that he will perform for this generation the service to astronomy performed by that indefatigable pioneer of several generations ago.

The book is really divided into two parts, the first half being a clear but brief introduction to the solar system, stars, and nebulæ, and closing with some reference to astronomical instruments. This is followed by several appendices, one of which, dealing with the constellations, occupies almost the remaining

half of the book and is really a star atlas for the naked eye observer in its own right.

The aim of the author is clear and praiseworthy, for in his own words, "astronomy is a pursuit which can never grow stale and which can provide endless hours of absorbing interest." In particular, he endeavours to get the armchair reader out of his armchair and into the starry evenings rather than leave him reclining, hence the emphasis on the more practical aspects of the subject from the point of view of the amateur. In this endeavour he should succeed admirably. The book is ideal for the beginner and can be recommended with confidence.

A few words of minor criticism could be mentioned. Firstly, it would be desirable for a list of well-known meteor radiants to appear separately as an appendix, rather than be scattered among descriptions of the various constellations, with possibly a cross reference to some mark on the constellation diagrams depicting the exact positions. Secondly, in view of the brevity of the chapters dealing with the solar system, etc., it would be helpful to add a short bibliography after each chapter on works of a more intermediate stage, which the beginner might pursue if need be, while lastly, the author might strive to expand the number of half-tone illustrations, which are rather lacking in this volume, and would do much to improve the appeal of any work of this nature.

L. J. C.

The Boys' Book of Rockets

(By Raymond F. Yates. T. Werner Laurie, London. Pp. 131, with 21 diagrams, and photographs. 8s. 6d. net.)

It would be unkind, perhaps, to suggest that the author was unfortunate in his choice of an artist (the diagrams are his own), or to remark that the young and hopeful peruser of a work published in 1950 is surely entitled to the knowledge that a two-step V-2 rocket has attained a height considerably in excess of the 114 miles reached at White Sands in 1946. But these are merely two of the sundry imperfections which give affront to the jaundiced eye. The credulous reader is asked to believe (p. 27) that the force of gravity on a planet is entirely dependent upon the planet's size; he is told (p. 118) that the V-1 is a rocket; he is informed (p. 119) that the exhaust velocity of the V-2 is 6,400 miles a minute; and he is invited to subscribe to the fallacy (p. 128) that the speed of a rocket cannot exceed that of its own exhaust.

Such minor blemishes, however, do not hide the fact that this English edition of an American work has much to recommend it. As an elementary introduction to astronautics, it treats of the various aspects of space travel with a pleasing lucidity which is sustained throughout. This having been said, it must be added that the final chapter, entitled *The Men Behind the Rockets*, leaves so much to be desired that its omission from the book would have been an improvement. Here, indeed, is a veritable monument of inadequacy. Pleading lack of space, the author limits himself to a mention of what he terms the "standouts"—and nominates von Eichstadt, de Fontana, Congreve, Betty, Kibalchich, Ziolkovsky, Goddard—and Whittle!

P. E. C.

A Concise History of Astronomy

(By Peter Doig, F.R.A.S. Chapman & Hall, London. 1950. Pp. 320. Illus. 21s.)

It is now many years since the publication of a reliable History of Astronomy, and the new book by Peter Doig, Editor of the *Journal of the British Astronomical Association*, fills a serious gap in the literature.

In addition to providing a concise and very readable account of the development of the world's oldest science—appreciation of which is essential for any real understanding of modern astronomy—the book gives, in the last hundred pages, an excellent summary of the present state of our knowledge. The whole book may be followed without difficulty by the layman, but will be equally valuable as a reference to more serious students. The print and presentation are extremely good.

There are a few small errors and omissions. Titan's diameter is wrongly given as 2,600 miles instead of 3,500 (p. 242); in describing lunar work of the present century, the 300-inch map of Wilkins should certainly have been mentioned (p. 209); Iapetus is the second brightest of Saturn's satellites, and was not one of those discovered by Herschel in 1789, as is implied on p. 127; the American astrophysicist Gamow is referred to as "Gamov"; and there are one or two unimportant misprints of dates. But these are but minor blemishes upon a work that should certainly be read by all those interested in Astronomy or Astronautics.

P. A. M.

CORRESPONDENCE

SIR,

Change of the Society's Name?

In reading the Journal of your Society I have been impressed by the faith which has preserved the name "Interplanetary" in spite of pressures from members of established engineering and scientific societies. There is little doubt that the appropriation of this word, which a few years ago might have seemed unpractically visionary, is now justified.

May I, however, draw attention to certain dangers in the preservation of the word "British" in the title of the Society. No one can now be in any doubt of the nationality of its officers and publications. Nevertheless, the way is at present left open for any grouping of persons in the United States or British Commonwealth to elect to call themselves the "Interplanetary Society." It would be a great pity if this happened, in view of the vision and enterprise shown by your Society in more difficult times.

Experience shows that professional societies which have sufficient foresight to form early are able to appropriate the most succinct titles; witness the Royal Society of London, which dropped the "London" and is now paralleled by many other Royal Societies with much more cumbersome names: such as Royal Society of New South Wales, Royal Society of Edinburgh; the Institution of Electrical Engineers which by an early start forced others to call themselves *American* Institution of Electrical Engineers, Institution of Engineers *Australia*, etc. On the other hand the U.S. got in first with the Institute of Radio Engineers, so that we now have the *British* Institution of Radio Engineers.

May I suggest therefore that you draw the attention of your Council to these points, if this has not already been done, and that the Society give careful consideration to the advisability of altering its name to "The Interplanetary Society."

CANBERRA, AUSTRALIA. D. F. MARTYN, F.R.S.

(*We shall be pleased to learn the views of other members on this interesting suggestion from Dr. Martyn and are grateful to him for his kind words about the Society.*—ED.)

SIR,

Lunar Spacesuit

Mr. Ross invites me to enlarge upon some of the suggestions made in my last letter and to demonstrate their practicability.

Firstly, on the calculation of radiative exchanges. Granted that the environment will be changing rapidly and incalculably, it is still possible to define the extremes of heat and cold which cannot be exceeded. Taking these extremes I showed in my first letter that replacing the cellular lagging of the spacesuit by two or three radiation screens gives effectively complete thermal insulation, which would, of course, cover all the intermediate conditions met in practice.

Secondly, I was careful to specify only that this form of lagging corresponds to the aluminium foil multilayer type. We must be grateful to Mr. Ross's well-developed sense of humour for the bizarre spectacle he conjures up of our first lunar explorers crackling across the surface of the Moon swathed in tinfoil! There are at least two practical possibilities. If the pressure in the suit makes it effectively rigid except where articulated, then there is no point in making the skin flexible. The rigid trunk and limb sections can then be treated (as Ross admits *re* the helmet) without difficulty, and a little ingenuity would cope with the articulations perhaps with fewer foils over their limited area. Alternatively, if the pressure effects do not annul the usefulness of a flexible skin, then it could be made up of several layers of a fabric with the high emissivity postulated in the original paper for the outer sheath. If the weave of adjacent layers were suitably oriented there would be very little effective thermal contact. It is perhaps worth noting that ordinary aluminised fabrics would be of little use in this work because the lacquer vehicle reduces the emissivity by a disproportionately large factor. The fabrics might perhaps be treated by the methods used to aluminise optical components.

Thirdly, the use of a cape to regulate temperature at night. Mr. Ross states that condensation on the cooled chest area could be avoided by a more complete removal of water vapour. The only place this can be removed to in the absence of condensation on the cooling surfaces is the CO_2 absorber. It seems likely that this extra load would impair the life of this unit by dissolving it away. In any case our explorer has to carry his automatic day-time cooler around so why not use it at night, too (on a much lighter duty) and he can then forget all about thermal problems.

Finally, the use of water as a refrigerant in this cooler. This need not reduce the temperature difference available for cooling. A little anti-freeze

in the evaporator will enable it to work below 0° C. on the refrigerant side if this is desirable, and moreover there would be very little anti-freeze lost in the vapour because of its low vapour pressure. The difficulties of obtaining steady boiling in this pressure range are, of course, quite real, but are not insuperable, and many large industrial distillation units operate in this region. The problem is greatly exaggerated in small tests and often disappears when transferred to a larger evaporater. Techniques are in use of artificially dirtying the apparatus to provide nucleation points. The economy in weight of refrigerant carried resulting from the use of water is of course a factor in permitting the continuous night and day use of the cooler. On balance I think that these last two changes (elimination of the cape and continuous use of the evaporative cooler with water as the working substance) add up to simplification rather than complication.

I hope that this enlargement on some of my original suggestions, whilst obviously not proving their practical value, may serve to show that they are worth following up in any practical work on the subject.

C. A. CROSS.

Northwich, Ches.

Mr. Ross writes:

"I find myself in general agreement with Mr. Cross over his two alternative spacesuit skin structures. However, I feel that a wholly rigid suit is to be avoided if at all possible, since, being unfoldable, it would occupy more stowage space than might readily be available. On the other hand, the vacuum-aluminised cross-weave cellular structure proposed by Mr. Cross seems to be an excellent suggestion.

"As regards use of the cape and condensation on the relatively cold chest area: it is true that the load on the chemical CO_2/H_2O absorber would be somewhat increased by more complete removal of water-vapour, and its operational life thereby reduced. However, I think possibly not to a serious extent.

"In any case, it will be noticed that the drawings show the cooling unit as being detachable: in short, not necessarily carried at night. . . . Still, if Mr. Cross insists, I have no objection to our explorer carrying it both by day and by night.

"The points mentioned by Mr. Cross in connection with use of water as the coolant are of very great interest, and are most encouraging. Unquestionably, water should be used if possible."

RECENT AND FORTHCOMING MEETINGS

December 14, 1950. "Interplanetary Travel," by G. V. E. Thompson, to the Wembley Branch, Association of Scientific Workers, at the General Electric Research Laboratories, North Wembley, Middx., at 7 p.m.

January 12, 1951. "Interplanetary Flight," by A. C. Clarke, to the Slough Astronomical Society, Slough, Bucks.

January 24, 1951. "Interplanetary Flight," by E. Burgess, to the Arts Club, Mosley Street, Manchester, 7 p.m.

February 6, 1951. "Into Space," by E. Burgess, to Chadderton Grammar School, Chadderton, Lancs., 5 p.m.

February 7, 1951. "Interplanetary Flight," by A. C. Clarke, to the Royal Aeronautical Society, Luton Branch, at 7.30 p.m.

February 22, 1951. "Interplanetary Travel," by M. W. Wholey, to the Windsor County Grammar School for Boys, 4 p.m.

March 17, 1951. "Film Show," to the Society at the Central Technical College, Suffolk Street, Birmingham, 6 p.m. *Admission is by ticket only.*

March 24, 1951. "Film Show," to the Society, at the Science Museum Lecture Theatre, Exhibition Road, South Kensington, S.W.7, 10.15 a.m. and 6 p.m. The former showing is mainly for visitors and interested non-members, while the evening showing is for members and their guests. *Admission is by ticket only* in the case of both performances.

March 31, 1951. "Film Show," to the N.W. Branch of the Society, at Adult Education Institute, 49, Lower Mosley Street, Manchester, 2, 2.15 p.m. *Admission is by ticket only.*

April 7, 1951. "Some Biological Problems of Space Flight," by Professor J. B. S. Haldene, to the Society, at Caxton Hall, S.W.1, 6 p.m.

April 21, 1951. "The Planet Mars," by H. L. Dilks, to the N.W. Branch of the Society, at 49, Lower Mosley Street, Manchester, 2, 7 p.m.

May 26, 1951. Short Paper and Discussion Evening by the N.W. Branch, at 49, Lower Mosley Street, Manchester, 2, Lancs., 7 p.m. **Note change of date from 19th May.**

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